Nebraska Water Resources Center
Annual Technical Report
FY 2010

Introduction

Dr. Bruce I. Dvorak took over as the interim director of the University of Nebraska Water Center as of September 2009. Lorrie Benson, J.D. serves as the assistant director. Steve Ress and Tricia Liedle serve as the communications specialist and program specialist, respectively. The Water Center staff also includes Rachael Herpel as the water outreach specialist. Duane Mohlman served as the data assistance coordinator through September 2010.

The Water Center is currently housed as part of the School of Natural Resources, located in Hardin Hall (3310 Holdrege, Lincoln, NE 68583-0979). The Water Center was the lead organizer for two major events fall 2010. First was a one-day science symposium showcasing water-related research and programming in Nebraska, as well as discussion of water management policies. The event, which was co-sponsored by the USGS Nebraska Water Science Center, featured keynote speaker Robert Hirsch, the noted USGS hydrologist. The second event was a one-day water law conference, designed for practicing attorneys, but attended by many water policy makers and managers. Also, the Water Center helped the UNL Office of Research host the second annual Water for Food conference in 2010.

The Water Center has continued to assist with development of the UNL water portal (water.unl.edu) and maintains the NIWR website (snr.unl.edu/niwr) through the Water Center. Along with these websites, we continue to focus on the Water Center’s home website (http://watercenter.unl.edu).

Research Program Introduction

For the 2010 fiscal year, four research seed grants received funding through the USGS 104(b) program. Areas chosen for funding were: (1) mitigate and treat antibiotic residues and antibiotic resistance genes in soil and water; (2) develop a wireless underground sensor networks for irrigation management; (3) investigating a new and potentially critical Cyanobacterial toxin in midwestern reservoirs; and (4) develop a groundwater recharge forecasting method for episodic recharge responses to weather events. An additional three seed research grants were selected for possible funding during the 2011 fiscal year. Areas chosen for 2011 were: (1) developing slow release persulfate to treat BTEX compounds at LUST sites; (2) high-resolution imaging of the Platte River streambed using combined electromagnetic induction and hydraulic parameter estimation techniques; (3) a cost effective fixed film atrazine treatment utilizing nitrate as a nutrient.

The Water Sciences Laboratory continues as a core facility to assist water science faculty. Analyses and the number of faculty utilizing this cutting-edge analytical facility continued to grow. The overall usage of the laboratory has increased by over 20% in the past three years. Once again, analyses were conducted for several other universities, state and federal agencies, as well as for private companies and individuals, but the focus remains on UNL faculty.

Most recently, UNL is in the process of forming the Water for Food Institute, with an emphasis on agricultural water management, based primarily on private fund contributions; the founding donation of $50 million was announced in April of 2010.

Cooperative Agreement No. 07HQAG0004 Incorporating Remote Sensing Information into the US Drought Monitor

Basic Information

Title:	Cooperative Agreement No. 07HQAG0004 Incorporating Remote Sensing Information into the US Drought Monitor
Project Number:	2006NE163S
Start Date:	4/1/2007
End Date:	3/31/2010
Funding Source:	Supplemental
Congressional District:	1
Research Category:	Climate and Hydrologic Processes
Focus Category:	Drought, None, None
Descriptors:	
Principal Investigators:	Mark D Svoboda

Publications

1. Gu, Y., Hunt, E., Wardlow, B., Basara, J., Brown, J., Verdin, J., 2008. Evaluation and validation of MODIS NDVI and NDWI for vegetation drought monitoring over the central Great Plains of the United States. Poster presented at the USGS Land Remote Sensing Symposium, 8-9 April, 2008, Flagstaff, Arizona.
2. Gu, Y., J.F. Brown, J. Verdin, and B. Wardlow. 2007. A five-year analysis of MODIS NDVI and NDWI for grassland drought assessment over the central Great Plains of the United States. Geophysical Research Letters, Vol. 34, L06047, 6 pages.
3. Nghiem, et al. (authors from JPL, USGS, NDMC, NOAA PSD, DFO, and others), “Pattern and Frequency of Soil Moisture Variability over the Continental United States,” manuscript in revision, 52 pp., 2009.
4. Nghiem, S. V., D. Balk, E. Rodriguez, G. Neumann, A. Sorichetta, C. Small, and C. D. Elvidge, “Observations of Urban and Suburban Environments with Global Satellite Scatterometer Data,” ISPRS Journal of Photogrammetry and Remote Sensing, doi:10.1016/j.isprsjprs.2009.01.004, 14 pp., in press, 2009.
5. Nghiem, S. V., and G. Neumann, “Remote Sensing of the Global Environment with Satellite Scatterometry,” keynote paper in Microwave Remote Sensing of the Atmosphere and Environment VI, ed A. Valinia, P. H. Hildebrand, and S. Uratsuka, Proc. of SPIE, Vol. 7154, 715402, doi:10.1117/12.804462, 11 pages, 2008.
6. Nghiem, S. V., “Satellite Remote Sensing of Soil Moisture for Drought Applications,” invited paper, National Integrated Drought Information System Knowledge Assessment Workshop – Contribution of Satellite Remote Sensing to Drought Monitoring, Boulder, Colorado, USA, 6-7 February 2008.
7. Nghiem, S. V., G. R. Brakenridge, and G. Neumann, “Drought, wetland, and Flood Monitoring with Satellite Scatterometer,” EOS Trans, AGU, 88(23), Jt. Assem. Suppl., Abst. U53B-05, May 2007.
8. Nghiem, S. V., G. R. Brakenridge, D. Cline, M. Dettinger, R. M. Dole, P. R. Houser, G. Neumann, E. G. Njoku, D. K. Perovich, K. Steffen, M. Sturm, J. Verdin, D. A. Wilhite, S. H. Yueh, and T. Zhang, “Global Observations of Land Surface Water with Satellite Active and Passive Microwave Sensors,” Satellite Observations of the Global Water Cycle, Irvine, California, 7-9 March 2007.

9. Brakenridge, G. R., S. V. Nghiem, E. Anderson, and R. Mic, “Orbital Microwave Measurement of River Discharge and Ice Status,” Water Resources Research, Vol. 43, W04405, doi:10.1029/2006WR005238, 2007.
10. Nghiem, et al. (authors from JPL, USGS, NDMC, NOAA PSD, DFO, and others), “Pattern and Frequency of Soil Moisture Variability over the Continental United States,” manuscript in revision, 52 pp., 2009.
11. Nghiem, S. V., D. Balk, E. Rodriguez, G. Neumann, A. Sorichetta, C. Small, and C. D. Elvidge, 2009. Observations of Urban and Suburban Environments with Global Satellite Scatterometer Data, ISPRS Journal of Photogrammetry and Remote Sensing, 64, 367-380.
12. Nghiem, S. V., and G. Neumann, “Remote Sensing of the Global Environment with Satellite Scatterometry,” keynote paper in Microwave Remote Sensing of the Atmosphere and Environment VI, ed A. Valinia, P. H. Hildebrand, and S. Uratsuka, Proc. of SPIE, Vol. 7154, 715402, doi:10.1117/12.804462, 11 pages, 2008.
13. Nghiem, S. V., “Satellite Remote Sensing of Soil Moisture for Drought Applications,” invited paper, National Integrated Drought Information System Knowledge Assessment Workshop – Contribution of Satellite Remote Sensing to Drought Monitoring, Boulder, Colorado, USA, 6-7 February 2008.
14. Nghiem, S. V., G. R. Brakenridge, and G. Neumann, “Drought, wetland, and Flood Monitoring with Satellite Scatterometer,” EOS Trans, AGU, 88(23), Jt. Assem. Suppl., Abst. U53B-05, May 2007.
15. Nghiem, S. V., G. R. Brakenridge, D. Cline, M. Dettinger, R. M. Dole, P. R. Houser, G. Neumann, E. G. Njoku, D. K. Perovich, K. Steffen, M. Sturm, J. Verdin, D. A. Wilhite, S. H. Yueh, and T. Zhang, “Global Observations of Land Surface Water with Satellite Active and Passive Microwave Sensors,” Satellite Observations of the Global Water Cycle, Irvine, California, 7-9 March 2007.
16. Brakenridge, G. R., S. V. Nghiem, E. Anderson, and R. Mic, “Orbital Microwave Measurement of River Discharge and Ice Status,” Water Resources Research, Vol. 43, W04405, doi:10.1029/2006WR005238, 2007.
17. Gu, Y., J.F. Brown, W. van Leewen, B.C. Reed, and T. Miura, 2009. Phenologic classification of the United States: a framework for extending a multi-sensor time series for vegetation drought monitoring, In Proceedings of the Annual Meeting of the Association of American Geographers, Las Vegas, Nevada.
18. Nghiem, et al. (authors from JPL, USGS, NDMC, NOAA PSD, DFO, and others), “Pattern and Frequency of Soil Moisture Variability over the Continental United States,” manuscript in revision, 52 pp., 2009.
19. Nghiem, S. V., D. Balk, E. Rodriguez, G. Neumann, A. Sorichetta, C. Small, and C. D. Elvidge, “Observations of Urban and Suburban Environments with Global Satellite Scatterometer Data,” ISPRS Journal of Photogrammetry and Remote Sensing, doi:10.1016/j.isprsjprs.2009.01.004, 14 pp., in press, 2009.
20. Nghiem, S. V., and G. Neumann, “Remote Sensing of the Global Environment with Satellite Scatterometry,” keynote paper in Microwave Remote Sensing of the Atmosphere and Environment VI, ed A. Valinia, P. H. Hildebrand, and S. Uratsuka, Proc. of SPIE, Vol. 7154, 715402, doi:10.1117/12.804462, 11 pages, 2008.
21. Nghiem, S. V., “Satellite Remote Sensing of Soil Moisture for Drought Applications,” invited paper, National Integrated Drought Information System Knowledge Assessment Workshop – Contribution of Satellite Remote Sensing to Drought Monitoring, Boulder, Colorado, USA, 6-7 February 2008.
22. Nghiem, S. V., G. R. Brakenridge, and G. Neumann, “Drought, wetland, and Flood Monitoring with Satellite Scatterometer,” EOS Trans, AGU, 88(23), Jt. Assem. Suppl., Abst. U53B-05, May 2007.
23. Nghiem, S. V., G. R. Brakenridge, D. Cline, M. Dettinger, R. M. Dole, P. R. Houser, G. Neumann, E. G. Njoku, D. K. Perovich, K. Steffen, M. Sturm, J. Verdin, D. A. Wilhite, S. H. Yueh, and T. Zhang, “Global Observations of Land Surface Water with Satellite Active and Passive Microwave Sensors,” Satellite Observations of the Global Water Cycle, Irvine, California, 7-9 March 2007.
24. Brakenridge, G. R., S. V. Nghiem, E. Anderson, and R. Mic, “Orbital Microwave Measurement of River Discharge and Ice Status,” Water Resources Research, Vol. 43, W04405,

doi:10.1029/2006WR005238, 2007.

25. Wardlow, B.D., T. Tadesse, J. Brown, K. Callahan, S. Swain, and E. Hunt, 2012. Integration of Satellite, Climate, and Biophysical Data for Drought Monitoring of Vegetation. In B. Wardlow et al. (Eds), Remote Sensing of Drought: Innovative Monitoring Approaches, CRC Press, Boca Raton, FL, In press.
26. Nghiem, S., B.D. Wardlow, D. Allured, M.D. Svoboda, D. LeComte, M. Rosencrans, S.K. Chan, and G. Neumann, 2012. Microwave remote sensing of soil moisture Science and Applications. In B. Wardlow et al. (Eds), Remote Sensing of Drought: Innovative Monitoring Approaches, CRC Press, Boca Raton, FL, In press.
27. Nghiem, S. V., J. Verdin, M. Svoboda, D. Allured, J. Brown, B. Liebmann, G. Neumann, E. Engman, and D. Toll, Improved Drought Monitoring with NASA Satellite Data, EWRI Currents, 12(3), 7, Amer. Soc. Civil Eng., Summer 2010.

National Drought Monitoring System for Drought Early Warning Using Hydrologic and Ecologic Observations from NASA Satellite Data—FINAL REPORT

Investigators: S. V. Nghiem (JPL, PI), J. P. Verdin (USGS, Lead Co-I), D. A. Wilhite (National Drought Mitigation Center or NDMC), R. Dole (NOAA Physical Science Division), D. LeComte (NOAA Climate Prediction Center), G. R. Brakenridge (Dartmouth College), E. G. Njoku (JPL)

Collaborators and NDMC PIs: Mark Svoboda (NDMC, Lead PI), Brian Wardlow (NDMC), Tsegaye Tadesse (NDMC), and Brian Fuchs (NDMC)

NATIONAL DROUGHT MITIGATION CENTER'S (NDMC) RESEARCH PROJECT PROGRAM, OBJECTIVES AND METHODOLOGIES

For the project ending December 2010, the NDMC has served as the project's lead integrator within the current operational U.S. Drought Monitor (USDM) framework (http://drought.unl.edu/dm). We have been tasked with ingesting results from our partners into the USDM (and National Integrated Drought Information System (NIDIS) Portal (http://drought.gov) where relevant) as a means of evaluating and improving decision support. Finally, we have attempted to help direct development and benchmark the results and value of our partner products within the USDM framework through case studies using the USDM and by soliciting and obtaining feedback from the USDM monitoring community (~275 members) including with the USDM authors themselves. In addition, the NDMC developed and currently houses and maintains the project's web site at: drought.unl.edu/nasa.

The general completed project tasks and deliverables meeting the role of the NDMC as defined above are outlined below:

1. **Provided guidance to establish data and processing requirements for the remote sensing products generated by the project participants for integration into the operational USDM system.**
    a. As products developed using the initial set of requirements (as defined by the NDMC/USDM) became available, the NDMC worked with the USDM authors and EROS, JPL and PSD to ensure they meet their operational needs. As an iterative process, adjustments and modifications were made to various products and deliverables based on this feedback process in order to ensure a more affective integration of the data into the USDM system and/or NIDIS Portal.
    b. Provided guidance/feedback on initial JPL and NOAA PSD derivative products involving the QuikSCAT SMC. Provided information on DM ranking percentile criteria, color scheme and USDM operational methods, delta maps and temporal production needs that will be applied to the SMC product.

c. Coordinated with USGS EROS and the High Plains Regional Climate Center (HPRCC) to establish automated delivery of current Standardized Precipitation Index (SPI) data that are acquired and ingested in the eMODIS system for near real-time VegDRI map production.
d. Defined the product requirements of the USDM for the soil moisture and VegDRI products in terms of data format, update schedule, and classification color scheme.
e. Assessed the initial eMODIS VegDRI and soil moisture products for drought monitoring as they became available.
f. Prepared and maintained a database of the input data used to develop the empirical-based eMODIS VegDRI models.
g. Worked with JPL and NOAA-PSD on feedback of the QuikSCAT derived SMC product (e.g., legend, incorporation of DM vector overlays, cartographic color scheme, and temporal updating) for presentation of case study results by JPL and for integration into the NIDIS Portal.

2. **Develop a centralized web location for USDM authors and project participants to access the NASA satellite-derived products**.
    a. The NDMC-NASA Partnership website (URL: http://drought.unl.edu/nasa) was developed and is currently hosted and maintained by the NDMC for project-related information. It has served as the central access point and repository for our partners' remote sensing-derived products, information and presentations, which were generated for the advanced USDM prototype system.
    b. Demonstrations of the advanced USDM system were conducted for all project partners and the USDM community once the feeds were established and automated from EROS and PSD to NIDIS.
    c. In Fall 2010, a time-series of eMODIS-based VegDRI maps were included in the website for evaluation by project participants and drought experts.
    d. In addition, the eMODIS-based VegDRI and initial prototype SMC delta maps were also posted within the USDM Authors' Community within the National Integrated Drought Information System's (NIDIS) U.S. Drought Portal (www.drought.gov) for authors to visualize the information in an interactive map viewer as a means of determining their validity and potential use in the making of the USDM. The eMODIS VegDRI continues to be fed to NIDIS and the USDM authors weekly while the SMC was interrupted with the interruption of the QuikSCAT data stream delivery.
    e. The NDMC will continue to update, enhance and maintain the project web site (http://www.drought.unl.edu/nasa/index.html) for project communication and to facilitate the integration of NASA Earth Science data into the USDM (ongoing) even after the project expires provided we have the in-house resources to leverage in doing so.

3. **Coordinate with USDM authors to implement remote sensing data product ingestion into an advanced USDM prototype environment.**
    a. The NDMC continually engaged the USDM authors to communicate and describe the informational content of each project deliverable (eMODIS VegDRI and SMC suites) as they became available and assisted them with the evaluation/integration of this information into the USDM development process and within the NIDIS Portal.
    b. Generated the series of VegDRI models and delivered them to USGS EROS for operational VegDRI production through USGS' eMODIS system.

4. **Benchmark existing and new USDM results to evaluate the improvements in the USDM map results produced using the advanced USDM prototype system.**
    a. The NDMC continually engaged and worked with the USDM authors to assess the enhancements provided by the remote sensing products in the development of the USDM maps.
    b. Case studies were undertaken with JPL and the SMC to evaluate how the SMC responded and helped determine its potential for being utilized within the USDM system. Interruption of the SMC creation due to sensor data issues led us to rely on case studied instead of an operational growing season approach as was envisioned at the beginning of the project. A full investigation into the viability of the SMC in enhancing the current system was not possible.

5. **Participate in a demonstration of the improved USDM prototype and distribute the improved drought products over the Internet to users via the NDMC web site**.
    a. Once activities 1 through 4 are completed, the NDMC will coordinate with project participants and USDM authors to communicate the improved USDM prototype at professional meetings and in the peer-reviewed literature to demonstrate the utility of remote sensing-based products derived from NASA satellite observations. The improved USDM drought products and supporting information will be made available to the general public via the NDMC-NASA Partnership website and/or NIDIS Portal when ready. In addition, progress and demonstration of the various deliverables (as they came on-line or required feedback) were presented at each of the Drought Monitor Forums during the life of the project.
    b. The eMODIS VegDRI has been made pseudo-operational and is being used weekly by the USDM authors and in the NIDIS Portal.
    c. Interruption of the QuikSCAT data stream made it impossible to integrate the SMC in the same manner as the eMODIS VegDRI above.

6. **Initiate the implementation of the prototype approach operationally at the end of Year 3**.
    a. The implementation of such an approach was dependent on the timely delivery of data products early in Year 3 in order to complete activities 1-5, which is required in advance of developing the operational phase of this project.

b. Again, eMODIS VegDRI was successful and the SMC was not.

7. **Presented project activities at numerous national and international conferences and for publications.**
    a. We are currently helping finish book chapters for VegDRI and SMC approaches for a new book entitled 'Remote Sensing of Drought: Innovative Monitoring Approaches' being prepared for CRC Press (co-editors: Brian Wardlow - NDMC, Jim Verdin – USGS & NIDIS, and Martha Anderson – USDA ARS) (May – Sept., 2009 – Wardlow)
    b. We are currently assisting JPL lead PI Nghiem in the writing and submission of a peer reviewed journal article on some of our project deliverables.
    c. Svoboda and Wardlow have presented on various aspects of the NDMC's role in this project at each of the Drought Monitor Forums over the past 3 years, which are held annually and bring in ~100 drought experts and media from Canada, Mexico and the United States.
    d. Potential continental/global applications have been discussed at these same USDM and North American Drought Monitor (NADM) Forums
    e. Project deliverables and products have been exposed to the NIDIS Program Office and presented at each of the NIDIS Pilot Drought Early Warning System (DEWS) basins for the Upper Colorado River, Apalachicola-Chattahoochee-Flint with plans to do the same for the California Pilot, scheduled to spin up in early 2011.

8. **The NDMC maintains an operational email list server to facilitate communication amongst all project participants (nasadrought@unl.edu) (ongoing).**

NIWR-USGS STUDENT INTERNSHIP PROGRAM

Not Applicable

STUDENT SUPPORT

Not Applicable

NOTABLE AWARDS AND ACHIEVEMENTS

Not Applicable

PUBLICATIONS AND PRESENTATIONS IN 2010

Wardlow, B.D., T. Tadesse, J. Brown, K. Callahan, S. Swain, and E. Hunt, 2012. Integration of Satellite, Climate, and Biophysical Data for Drought Monitoring of Vegetation. In B. Wardlow et al. (Eds), *Remote Sensing of Drought: Innovative Monitoring Approaches*, CRC Press, Boca Raton, FL, In press.

Nghiem, S., B.D. Wardlow, D. Allured, M.D. Svoboda, D. LeComte, M. Rosencrans, S.K. Chan, and G. Neumann, 2012. Microwave remote sensing of soil moisture – Science and Applications. In B.

Wardlow et al. (Eds), *Remote Sensing of Drought: Innovative Monitoring Approaches*, CRC Press, Boca Raton, FL, In press.

Nghiem, et al. (authors from JPL, USGS, NDMC, NOAA PSD, DFO, and others), “Pattern and Frequency of Soil Moisture Variability over the Continental United States,” *manuscript* in revision, 52 pp., 2011.

Nghiem, S. V., J. Verdin, M. Svoboda, D. Allured, J. Brown, B. Liebmann, G. Neumann, E. Engman, and D. Toll, “Improved Drought Monitoring with NASA Satellite Data,” *EWRI Currents, 12*(3), 7, Amer. Soc. Civil Eng., Summer 2010.

Nghiem, S. V., D. Balk, E. Rodriguez, G. Neumann, A. Sorichetta, C. Small, and C. D. Elvidge, “Observations of Urban and Suburban Environments with Global Satellite Scatterometer Data,” *ISPRS Journal of Photogrammetry and Remote Sensing*, 64, 367-380, doi:10.1016/j.isprsjprs.2009.01.004, 2009.

Nghiem, S. V., and G. Neumann, “Remote Sensing of the Global Environment with Satellite Scatterometry,” keynote paper in *Microwave Remote Sensing of the Atmosphere and Environment VI*, ed A. Valinia, P. H. Hildebrand, and S. Uratsuka, *Proc. of SPIE*, Vol. 7154, 715402, doi:10.1117/12.804462, 11 pages, 2008.

Wardlow, B.D., GIScience Activities at the National Drought Mitigation Center, *USDA National Agricultural Statistics Service (NASS)*, Fairfax, VA., August 12, 2010.

Wardlow, B.D., An Overview of Remote Sensing Activities at the National Drought Mitigation Center, *Hydrology and Remote Sensing Laboratory, USDA Agricultural Research Service (ARS)*, Beltsville, MD, August 11, 2010.

Wardlow, B.D., The Future of Remote Sensing Applications for Drought Monitoring, *World Meteorological Organization (WMO) Drought Workshop*, Lincoln, NE, December 10, 2009.

Wardlow, B.D., Vegetation Drought Response Index (VegDRI): 2009 Update and Ongoing Activities, *U.S. Drought Monitor Forum*, Austin, TX, October 8, 2009.

Wardlow, B.D., Remote Sensing and Drought – An Overview and Opportunities for Mali, *WMO Drought Workshop*, Bamako, Mali, September 17, 2009.

Wardlow, B.D., Remote Sensing and Drought Monitoring – New Tools and Future Directions, *National Hydrologic Warning Council Conference*, Vail, CO, May 5, 2009.

Wardlow, B.D., VegDRI – A New Hybrid Drought Index for Monitoring Vegetation in the U.S., U.S.-Canada GEO Bilateral Workshop on Ice and Water, National Science Foundation (NSF), Arlington, VA, October 28, 2008

Wardlow, B.D., Vegetation Drought Response Index (VegDRI): A Hybrid-Based Approach for Vegetation Drought Monitoring, North American Drought Monitor Workshop, Ottawa, Canada, October 16, 2008.

How Water Resources Limit and/or Promote Residential Housing Developments in Douglas County

Basic Information

Title:	How Water Resources Limit and/or Promote Residential Housing Developments in Douglas County
Project Number:	2008NE164B
Start Date:	3/1/2008
End Date:	3/30/2010
Funding Source:	104B
Congressional District:	2
Research Category:	Social Sciences
Focus Category:	Economics, Floods, Management and Planning
Descriptors:	floodplains property values, dam construction lakeview amentities
Principal Investigators:	Steven Shultz

Publications

1. Shultz, S, and N. Schmitz, 2008.. Viewshed Analyses to Measure the Impact of Lake Views on Urban Residential Property Values. The Appraisal Journal: 76(3): 224-232.
2. How Water Resources Limit and/or promote Residential Housing Developments in Douglas County. 2008. Shultz and Schmitz. http://unorealestate.org/pdf/UNO_Water_Report.pdf
3. Shultz, S, and N. Schmitz, 2008.. Viewshed Analyses to Measure the Impact of Lake Views on Urban Residential Property Values. The Appraisal Journal: 76(3): 224-232.
4. How Water Resources Limit and/or promote Residential Housing Developments in Douglas County. 2008. Shultz and Schmitz. http://unorealestate.org/pdf/UNO_Water_Report.pdf

Final Project Report

U.S. Geological Survey 104 B Program (through the NU Water Center)
March 30, 2010

How Water Resources Limit and/or Promote Residential Housing Developments in Douglas County

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Douglas County, NE Board of Commissioners

Any and all claims and statements made in this report along with any potential omissions or errors are the sole responsibility of the authors

Executive Summary

Objectives:

This research quantifies the relationships between water resources and residential property values in the Greater Omaha metropolitan area by measuring the impact of:

1. 100-year floodplain designations on residential housing prices to evaluate potential economic benefits of flood mitigation projects.

2. Man-made lakes on nearby residential property prices to identify strategies to maximize public benefits.

3. Alternative types of open space/low impact development (LID) subdivision designs on residential property values. This will help both the public and private sector better understand and promote successful and profitable LID subdivisions.

These analyses are expected to be of interest to both policy makers and resource managers in their ongoing efforts to design and implement cost-effective flood mitigation and stormwater water management projects in Douglas County.

Approaches:

The methodological approach of this study relied on empirical real estate transaction data that was referenced within a geographical information system (GIS) in order to quantify site-specific relationships between water resources and property values. In particular, hedonic price models (also known as 'mass appraisal' models) were estimated along with comparisons of the sale prices of residential lots. Earlier phases of this research have already been accepted for publication in peer-reviewed professional journals.

Results 1: Floodplain Impacts and Residential Property Values

Hedonic price models indicate that homes within Douglas-Papio Creek floodplains100-year floodplains have sold for 3.9% less than otherwise similar but non-floodplain homes over the 1996 to 2007 time period. Based on these hedonic price impacts in conjunction with the estimated market value of all 1,123 Douglas-Papio floodplain homes, a hypothetical set of upstream flood mitigation projects which would remove all of these homes from the floodplain, would generate $5.3 million in increased property values.

Alternatively, potential flood mitigation benefits were also calculated based on the estimated cost of flood insurance premiums: $11.9 million for all Douglas-Papio floodplain homes versus $360,000 for only the homes designated to be in the newly revised floodplain in 2008 (based on 'grandfathered' non-floodplain insurance rates which are about 75% cheaper than typical 100-year floodplain rates).

These property valuation estimates related to floodplain status, could potentially be used by Douglas County for evaluating the economic feasibility of proposed flood mitigation projects in the Papio Creek Watershed. In particular, if it is known how proposed flood mitigation projects impact downstream floodplains (i.e. the number of homes removed from the 100-year floodplain), then either expected property value increases or avoided flood insurance could be considered as flood mitigation benefits. For example, depending on the likely effectiveness of a flood mitigation project, and the type of benefits deemed most appropriate for comparison, a range of possible economic benefits associated with future (hypothetical) Douglas-Papio Creek flood mitigation projects emerges: The low end of the range is $36,000 in benefits associated with a scenario of only 10% of homes being removed from the Douglas-Papio Creek floodplains, and considering only new insurance costs to homes placed in the floodplain in 2008-09. The high end of the range is $11.9 million based on avoided flood insurance when 100% of Douglas-Papio Creek residential properties are removed from the floodplain. This information could potentially be used in conjunction with results of hydrologic-based feasibility studies (by others) to evaluate the economic feasibility of proposed flood mitigation projects in Douglas and/or Washington County. However, two other key property types should be included in such analyses: Commercial property which is likely more valuable than residential property within these floodplains, and undeveloped land which would likely increase in value if it is removed from the 100-year floodplain.

Results 2: Amenity Values Created by Lakes

Hedonic valuation models of residential housing sales along with comparative lot sale analyses have demonstrated that substantial increases in residential property values have resulted from the construction of four different man-made lakes in the Omaha area. Lake views increase housing values by between 7% and 18% at the four different lakes and has created $26.7 million in increased housing values. Both view and access premiums are paid by home and/or lot buyers and based on the analyses of lot sales at two lakes, most of these premiums appear to be captured by landowners and/or developers at the time the lakes are first constructed. It is also evident that increased levels of exclusivity increase the premiums that homebuyers are willing to pay for both lake views and access.

An analysis of ‘Dam Site 13’ (the most recently constructed Omaha lake and the first ‘public-private lake construction partnership’), demonstrated that the private sector partner contributed $1.6 million to the cost of lake construction and in return, is *expected* to generate an additional $7.7 million from incrementally higher lot sale values associated with view and access premiums. This corresponds to a discounted rate of return of 437% or, 87% annually for five years. These are *preliminary* estimates of potential profit levels and continued research on this topic is warranted particularly since it is suspected that part of the lot values in this subdivision may be due to proximity to a school and/or a very high quality subdivision design.

It was concluded that future public-private lake construction partnerships should more closely evaluate whether contributions from private developers are sufficient in relation to the increased profit levels associated with lake views and/or access that they are likely to capture. Alternatively, the design of future lakes should have more public recreation and buffer areas that improve both access and lake water quality in order to guarantee the public fully captures lake amenity values that are created through the use of public funds.

Results 3: LID Subdivision Design and Property Values

A set of 14 different hedonic valuation models were estimated across 326 different subdivisions in the western and southwestern (suburban) portions of Douglas County in order to quantify how different types of open space characteristics, which are considered a proxy for alternative LID designs, impact residential property values. From this it was concluded that homeowners:

- Are willing to pay more for a home near open space if the open space is owned and/or managed by private versus a public entity.
- Prefer open space that is dominated by trees and mowed grasses over non-mowed areas, or open spaces with recreation (sports) facilities.
- Prefer open space with trails.
- Are willing to pay 1.1% more for clustered open space (LID) designs, and, 2.74% more for open (contiguous) open space (LID) designs than they would for conventional sub-division designs.

These research results should be useful to both public planners and private developers in the design and implementation of open space and LID subdivision designs within residential subdivisions. In particular, price premiums associated with alternative open space or LID subdivision designs can now be compared to their implementation costs and relative effectiveness for stormwater management.

Where These Research Methodologies Have Already Been Peer Reviewed

Shultz, S. and N. Schmitz. 2008 (forthcoming). Augmenting Housing Sales Data to Improve Hedonic Estimates of Golf Course Frontage. ***Journal of Real Estate Research.***

Shultz, S, and N. Schmitz, 2008. Viewshed Analyses to Measure the Impact of Lake Views on Urban Residential Property Values. ***The Appraisal Journal*** **(Summer, 2008).**

Shultz, S. and P. Fridgen. 2001. "Floodplains and housing values: Implications for flood mitigation projects". ***Journal of the American Water Resources Association*** 37(3)

Shultz, S. and D. King. 2001. "The use of census data for hedonic price estimates of open space amenities and land uses". ***Journal of Real Estate and Finance Economics*** 22(1)

Suggested Follow-Up Research

The original study objectives specified in the contract between UNO, Douglas County, and the NU Water Center, are considered to have been met by this Final Project Report. However, the UNO research team plans to conduct follow-up research on the various suggested future research topics listed below (categorized by floodplain, lake amenities, and LID research themes). No additional funds are being requested from the sponsors for this continued research, and the resulting research results will be considered 'supplemental reports' and distributed to the Douglas County Board and the NU Water Center when they are completed (likely in the next 6 to 12 months).

Floodplain-Property Value Research

1) Conduct comparable sales based appraisal analyses.
2) Evaluate strategies to improve flood insurance cost estimates.
3) Conduct surveys of floodplain property owners.
4) Estimate the impact of floodplain status of commercial properties and for undeveloped land.
5) Determine total (residential, commercial and vacant) property values and related flood mitigation benefits in the Douglas-Papio floodplains

Lake-View Amenities

1) Conduct a hedonic analysis of sold lots at Standing Bear, and Zorinsky to better measure view and access values that were captured by developers
2) Continue to collect and monitor both lot and housing sales at Dam Site 13 to see if view and access premiums change over time
3) Conduct surveys of homebuyers at Dam Site 13 and nearby subdivisions to identify factors that may have influenced their purchase decisions and in particular, to assess the importance of lake views, access and other factors.

LID/Open Space Amenities

1) Replicate the open space hedonic price models using lot sales. This would potentially be more helpful for residential housing developers to identify different profit levels associated with different open space designs

2) Survey homebuyers to elicit their perceptions of and preferences for different open space amenities. This could potentially confirm many of the conclusions reached in this study based on observed property sales data

Table of Contents

The Impact of Floodplains on Residential Property Values

Background

The hedonic valuation method is a widely accepted approach to quantify the determinants of property values and for measuring the marginal contribution of environmental amenities (or disamenities). It relies on multiple regression where the dependent variable (usually housing price) is specified to be a function of structural housing characteristics, lot characteristics, neighborhood effects, transaction details (including time of sale), and environmental conditions. When the hedonic approach is used to quantify how floodplains impact residential property values, a dichotomous ('dummy') variable usually represents whether a property (usually a building) is located in the floodplain.

There are several reasons why it is important to quantify the relationship between 100-year floodplain status and property values. First, homeowners, appraisers and tax assessors regularly need such information to better understand how floodplain status affects the market value of residential properties. Second, such information can be used to help quantify the economic benefits associated with flood mitigation projects which are proposed to remove particular residential properties from the 100-year floodplain. Finally, an improved understanding of the relationship between floodplains and property values could potentially be used to determine how much individual floodplain property owners should contribute to the cost of specific mitigation projects which will potentially remove their properties from the floodplain and hence increase their property values.

It is expected that the development and refinement of methodologies to quantify the impact of floodplains on property values is particularly relevant in the Greater Omaha metropolitan area where 100-year floodplain maps have recently been re-drawn by the Papio-Missouri Natural Resource District (PMNRD) and the Federal Emergency Management Agency (FEMA). These new floodplain maps will become official by the end of 2008 or early 2009. The construction of new homes is not permitted in the 100-year floodplain but existing homes in these high flood-risk areas are usually permitted to remain in existence and can be re-sold as long as their floodplain status is disclosed to potential homebuyers. Also, flood insurance administered by the National Flood Insurance Program (NFIP) is required for such homes by mortgage lenders. Preliminary estimates by the PMNRD indicated that there are about 2,600 properties in the 100-year floodplain (Douglas and Sarpy counties) and that approximately 700 to 900 of these properties have been designated to be included in the 100-year floodplain as a result of the new (2008-09) floodplain maps (PMNRD Spectrum Newsletter, Summer, 2007).

The impact of floodplain location on property values in Omaha has to date not been formally studied. In fact, the closest known location of a published hedonic floodplain study is Fargo, North Dakota, where it was determined that homes in the 100-year floodplain lowered home values by between 8.8% and 10.2% (Shultz and Fridgen, 2001). Another study in a suburban watershed in St. Louis, MO, measured a 4.7% floodplain impact on housing prices (Qui, Prato and Boehm, 2006). Negligible floodplain impacts have been noted in other regions, particularly in areas with high profile and recent flood events have not occurred and/or where homebuyers are not fully informed of the floodplain status of their homes prior to purchases (Chivers and Flores, 2002).

Study Objectives

1) Quantify Floodplain Impacts on Property Values

A hedonic price model is estimated to quantify the determinants of housing prices with a particular focus on the marginal impact of 100-year floodplain status. The study sample is a two-mile buffer around the Big, Little, and West reaches of the Papio Creek within Douglas County (hereafter referred to as the ‘Douglas-Papio Creeks’). This study area was chosen since the Douglas-Papio Creeks contain the highest relative concentrations of floodplain properties in Douglas County, and because the Papio Creeks are the focus of several recently proposed flood mitigation projects.

2) Determine the Market Values of Floodplain Properties

Using Douglas County tax assessment records and GIS-based analyses of housing structures within FEMA D-Firm floodplain maps the market value of all residential properties within the current and proposed (2008-09) Douglas-Papio Creek floodplains are estimated. This is based on ratios between assessed and sale values and site specific determinations of the floodplain status of individual homes.

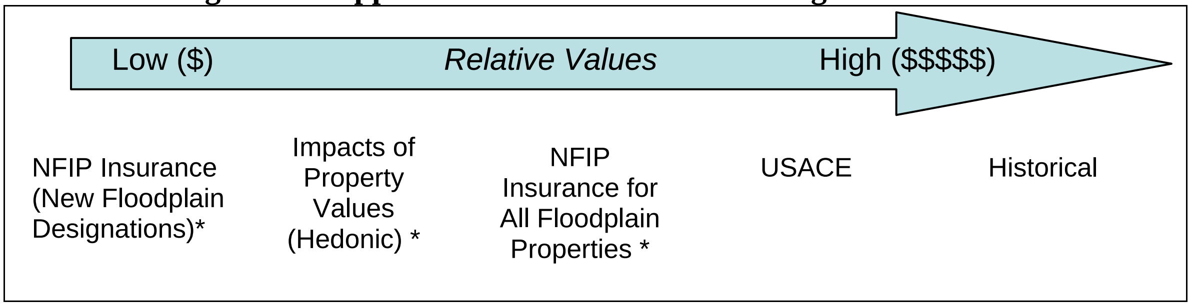
3) Estimating Potential Flood Mitigation Benefits

Here the potential economic benefits associated with flood mitigation projects that eliminate the 100-year floodplain status of residential properties in the Douglas-Papio Creek floodplains are calculated based on alternative criteria: a) Observed marginal impacts of floodplain location on property values; b) Flood insurance premium costs associated with all residential floodplain properties; and c) Flood insurance premiums costs only for homes designated to be in the new (2008-2009) 100-year floodplain.

In addition to identifying potential property value losses associated with floodplains, this research effort will demonstrate an approach for calculating the potential financial benefits which individual property owners could capture as a result of flood mitigation projects. This in turn could become a mechanism for objectively calculating special assessment taxes on these property owners who would directly benefit from specific flood mitigation projects and hence reduce the financial burden of such projects on taxpayers who will not receive any direct flood mitigation benefits.

It should be noted that there are other approaches used by policy makers to quantify flood mitigation benefits that were not evaluated by this present research. These include quantifying actual flood damage after specific flood events (i.e. historical flood data), and/or the standard USACE approach to quantifying potential flood damages which involves determining the value of first floor residential structures and a fixed amount of personal contents measured as percentage of structural value that would be potentially damaged during a 100-year flood events. The relative values of estimated flood mitigation benefits associated with each approach are shown in Figure 1.1. Insurance cost savings for homes determined to be in the 100-year floodplain after an earlier home purchase generate the lowest expected economic values, while observed historical flood damages are expected to generate the highest values flood mitigation benefits.

Figure 1.1. Approaches to Estimate Flood Mitigation Benefits



** Indicates approaches/values quantified by this present study*

The selection of a particular type of flood mitigation benefit for use in a cost-benefit analysis (CBA) of a specific flood mitigation project depends on which approach or value is most suitable from the dual perspectives of: 1) Reliability of data and estimation approaches (usually a function of available data); 2) Who is expected to received flood mitigation benefits (i.e. from whose perspective is the CBA being analyzed)?

For example, from the federal government's perspective, the use of the standard USACE inventory-based approach is likely the most appropriate as it accounts for damages from a wide societal perspective. In cases where extensive flood damage has occurred the use of historical data has benefits particularly for local and state governments who often want to determine how much flood damage has occurred above and beyond what is covered by flood insurance of other related federal emergency relief programs. Flood reduction benefits based on avoided flood insurance premiums primarily accounts for benefits captured by individual property owners (who may no longer be required to purchase flood insurance as the result of a specific flood mitigation project). Similarly, marginal property value impacts associated with flood reduction are also usually captured by, and of most interest to, private property owners. However, these price impacts usually generate lower flood reduction benefits due to the fact that many homebuyers either do not understand the present value of a future stream of insurance premium costs, or, they are not aware of floodplain risks. The final and lowest expected relative benefit associated with flood reduction is avoided flood insurance for properties placed into the floodplain after purchasing their homes (i.e. when floodplain maps are updated by FEMA). Although these are captured by private property owners, these benefits and costs are often of societal concern under the premise that such property owners did not voluntarily purchase floodplain properties.

Historical damage data does not exist in sufficient frequency or detail in the Douglas-Papio Creek floodplains and the estimation of potentially avoided flood damage using the USACE approach requires information and data associated with flood mitigation projects and specifically impacted properties. However this information can be very difficult and time consuming to accurately estimate. As well, most of these USACE flood reduction benefits should be accounted for by the avoided insurance approach. Therefore, this study concentrates on the remaining three approaches: property price impacts (hedonic-based estimates), flood insurance for homes in the original 100-year floodplain, and alternatively, in the new (2008-09) floodplain.

Methods and Procedures

Hedonic Price Impacts of Floodplains

The hedonic price analysis quantifies the impact of the 100-year floodplain on residential housing sale prices within 2 miles of Douglas-Papio Creeks over the 1996 to 2007 time period. The study area includes the Big, Little, and West reaches of the Papio Creek within Douglas County (Figure 1.2). There are approximately 7,200 acres of existing (pre 2008) floodplains within this study area. The corresponding floodplain area in the Sarpy county portions of the Papio Creeks is approximately 6,200 acres.

Figure 1.2 Douglas-Papio Creek Study Locations

The real estate transaction dataset used for the study was generated by combining a Douglas county parcel database with real estate transaction data from the Great Plains Realtors Multiple Listing Service (MLS) over the January 1996 – June 2007 time-period. The MLS data was deemed necessary to account for detailed structural housing characteristics and transaction information (particularly the existence of any seller concession). The resulting database includes 22,350 arms-length sales.

Since the database was in a GIS format, it was possible to determine whether homes were within FEMA 100-year floodplain zones (zones A, AE, AJ and AO) based on spatial overlays of residential parcels and both original and 2008-09 FEMA floodplain maps (which were provided to us in a GIS format by the PMNRD). The identification of the floodplain status of sold residential properties first involved a spatial overlay of floodplain and parcel boundaries and then manual (visual-on-screen) inspections of house locations and floodplain boundaries using NAIP air-photos. This manual approach was necessary since while a lot may be in the floodplain, flood insurance is only required if the actual house boundary is located in the floodplain and because the GIS database of properties does not explicitly contain the boundaries of housing structures. The resulting map contained in Figure 1.3 shows the locations (in red) of all the floodplain homes sold between 1996 and 2007 within the study area. Examples of the manual (property-by-property) analyses of whether homes were in or out of the floodplain (both the old floodplain and the revised 2008-09 floodplain) are show in Figure 1.4.

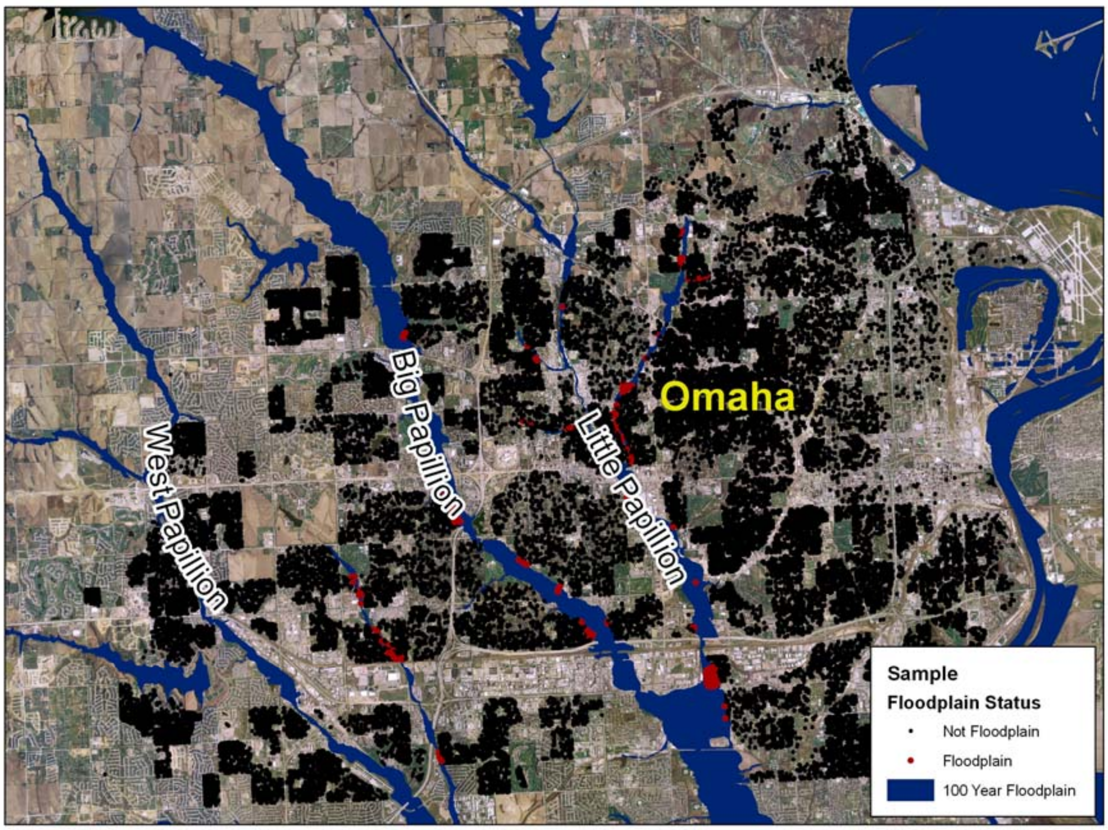


Figure 1.3 Sold Homes and Papio Creek 100-year Floodplain (1996-2007)

A. A Modern Subdivision Partially in the Original 100-Year Floodplain

B. Homes Previously Not in the Floodplain but now in the Year 2008 Floodplain (red areas)

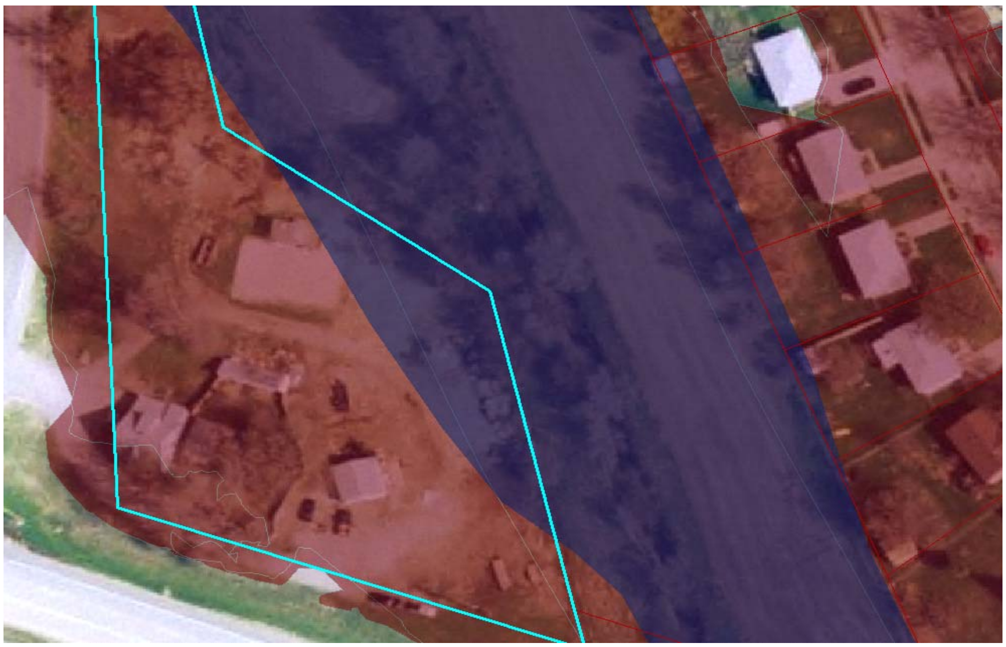


Figure 1.4 Examples of Sold Douglas County Floodplain Homes

GIS techniques were also used to quantify how far floodplain homes were from major roadways and/or, industrial areas, and water features (streams and/or impounded water bodies). The full range of explanatory variables used in the hedonic price model is summarized in Table 1.1. The functional form used to represent the relationship between particular explanatory variables and housing prices varies based on the literature (previous studies) and our own experiences with hedonic price modeling in Omaha. Log terms are used with lot size, house size, distance to water, and distance to industrial locations in that the marginal effects of these characteristics are less as the magnitude of the variable gets larger, i.e. diminishing marginal returns.

With respect to the floodplain explanatory variable (whether or not a property is located within the floodplain) log-linear functional form is used. Therefore the resulting coefficient can be interpreted directly as percentage change in sale price resulting from whether or not a home is located in the 100-year floodplain. It has been pointed out previously by Kennedy (1981) that the interpretation of log-linear coefficients must be adjusted for by using the following equation: $\hat{g} = e(\hat{c} - (\frac{1}{2})V(\hat{c})) - 1$ where $\hat{g}$ is the percentage effect of the dummy variable as adjusted by the variance of the coefficient $V(\hat{c})$.

The Market Value of Floodplain Homes

The market value of residential properties in the 100-year floodplain portions of the Douglas-Papio Creeks was estimated by cross listing Douglas County tax assessment records and our GIS based analyses of housing structures within the most recent FEMA floodplain maps. After quantifying sale assessment ratios of Papio Creek floodplain homes in Douglas County (i.e. comparing assessed values to actual sale prices while accounting for any potential seller concession), the reciprocal of these ratios are multiplied by the aggregate (total) assessed values of all residential properties in the Douglas-Papio Creek floodplains to generate an estimate of the market value of all residential properties both within the original and the revised (2008-09) floodplains.

Table 1.1. Variables in the Douglas County Hedonic Price Model

Variable Name	Definition	Functional Form Used	Expected Sign (impact)
1) Dependent Variable (Y)			
Adjusted Price	Sale Price minus any seller concessions ($)	(log Price)	
2) Explanatory Variables			
D Floodplain	In the 100-year floodplain? (yes/no)	linear	-
Industry	Distance to Industrial Land Uses (ft)	log	+
Road	Distance to Major Road (ft)	Linear	+
Water	Distance to Water Body	Log	-
House Size	Finished House Size (sft)	Log	+
LotSize	Lot Size	Log	
Age	The home age (years)	Linear	-
Fireplaces	Number of fireplaces	Linear	+
Garage Spaces	Number of garage stalls	--	+
Bathrooms	Number of bathrooms	Linear	
DAvg	Home is average condition	Linear	+
DAboveAvg	Home is above avg. condition	Linear	+
Year	Year of Sale 1999-2007	Linear	Varies

Potential Flood Mitigation Benefits

The potential economic benefits associated with hypothetical flood mitigation projects that result in the elimination (removal) of the floodplain designation for residential properties in Douglas-Papio Creek floodplains involves using all the previously generated information on floodplain price impacts, floodplain properties and the market value of floodplain properties.

The marginal benefits of homes potentially removed from the floodplain based on estimated hedonic price estimates (i.e. homebuyer preferences) account for increases in property values (i.e. likely selling prices) resulting from the floodplain status of homes being eliminated. In particular, marginal price impacts of floodplains are multiplied by estimates of the total property value of all Douglas-Papio Creek floodplain homes.

Estimates of the present value of floodplain insurance premiums they are assumed to no longer be required for Douglas-Papio Creek floodplain homes in the original 100-year floodplain first requires multiplying the assessed values of homes (buildings only) by an estimated average cost of a floodplain policy that covers the building and personal contents valued at 30% of building value. These flood insurance costs were obtained from the National Flood Insurance Program website of FEMA (NFIP, 2008) and should be considered only approximate estimates for floodplain insurance costs for properties located in floodplain zones A, AE, AJ and AO. In reality, premiums are based on site specific home and site data. To determine the present value of insurance premiums over time, annual premiums are discounted over a 30-year period using a 7% discount rate.

Flood insurance premium costs for homes designated to be in the new (2008-09) 100-year floodplain are assumed to be 25% of the cost of flood insurance associated with the original 100-year floodplain. This is due to the widely known loophole that allows homeowners in the new floodplain designation to obtain a flood insurance policy based on the previous (non-floodplain) status prior to the official approval of revised and expanded floodplain maps.

Results

Properties in the Douglas-Papio Creek Floodplains

A total of 1,643 residential homes were found to potentially be in the Douglas-Papio Creek 100-year floodplain (based on original and new 2008 floodplain maps). Visual (GIS-based) inspections of individual homes found that only 1,123 (or 68%) of these homes were actually in the floodplain (i.e. parts of the property lot may have been in the floodplain but the house structure itself was not).

Over the 1996 to 2007 time-period, 243 Douglas-Papio Creek floodplain homes with lots (in the original, pre-2008 floodplain) were sold through the MLS and manual inspections of house locations determined that only 200 (82%) of these homes were actually located in the floodplain. The characteristics of floodplain versus non-floodplain homes sold over this period are summarized in Table 1.2 Floodplain homes are on average priced 16% lower than sold non-floodplain homes, but these homes were also smaller and had fewer fireplaces, garage spaces, and bathrooms. However, floodplain homes on average have larger lot sizes and were farther from major roads or industrial areas, and were closer to water bodies. The advantage of using a hedonic price equation to quantify the marginal effect of floodplain location on sale prices is that it controls for different characteristics of properties.

Hedonic Price Estimates of Floodplains

The multiple regression model summarizing the hedonic floodplain results is summarized in Table 1.3. All of the explanatory variables in the model are statistically significant at the 90% confidence level or higher and have the expected directional impact on property values. The R^2 of the model is 0.79 meaning that 79% of the variation in price is explained by the model and the F-statistic was significant at the 1% level indicating that all variables considered jointly have a statistically significant impact on sale prices.

Coefficients for non-linear variables (with logs) need to be numerically manipulated before directly interpreting their marginal effects on sale price but the linear coefficients can be interpreted directly. For example, each additional year of age decreases a home’s sale price by 0.3% while each additional bathroom contributes 4.2% and an ‘above average condition home would be worth around 15% more than an otherwise similar home. The dummy variable coefficient for floodplain location was negative and statistically significant and indicates that floodplains reduce property values by 3.9% (based on both the original coefficient and the Kennedy coefficient transformation).

This floodplain price discount of 3.9% observed in Douglas County is substantially lower than floodplain impacts noted in other locations of the country and appears to be considerably less than the present value cost of flood insurance premiums that are required for mortgage loans. There are three possible explanations for this. First, these homes may have natural resource amenities that are not being fully accounted for in our model. That is, homebuyers may be overlooking floodplain risk because these homes are on large lots with streams and/or nearby other open space amenities (views, wildlife etc). A second possible explanation is homebuyers may not be fully aware of the full extent of floodplain risks in light of the fact that no major flood events have occurred in the region in recent years. Third, homeowners may not fully understand the present value costs of flood insurance premiums required over time.

Table 1.2 Floodplain/Non-Floodplain Housing Sale Characteristics (Douglas-Papio Floodplain, 1996-2007)

Variable	Non-Floodplain Sales(n=22,150)				Floodplain Sales (n= 200)			
	Mean	Median	Min	Max	Mean	Median	Min	Max
Adjusted Price	$138,413	$123,000	$14,000	$899,000	$100,803	$95,000	$26,759	$212,500
Industry	4,450	3,448	38	16,462	2,437	2,120	139	6,291
Road	804	720	30	2,616	838	823	85	2,460
Water	2,185	1,904	27	7,606	517	372	53	4,764
LotSize (sqft)	10,045	8,712	0	460,429	9,322	7,841	2,178	62,726
HouseSize (sqft)	1,900	1,724	400	6,511	1,453	1,415	750	3,698
Age [Years]	34.3	33.0	0.0	136.0	38.1	41.5	0.0	96.0
Fireplaces	0.73	1.00	0.00	4.00	0.34	0.00	0.00	2.00
Garage Spaces	1.73	2.00	0.00	4.00	1.35	1.00	0.00	4.00
Bathrooms	2.42	2.00	0.00	4.00	1.81	2.00	1.00	4.00
D Avg.*	0.32	0.00	0.00	1.00	0.44	0.00	0.00	1.00
D Above Avg.*	0.34	0.00	0.00	1.00	0.20	0.00	0.00	1.00
D 1997 to D 2007 (% Sold in)	0.07	0.00	0.00	1.00	0.06	0.00	0.00	1.00
D 1998	0.08	0.00	0.00	1.00	0.09	0.00	0.00	1.00
D 1999	0.08	0.00	0.00	1.00	0.06	0.00	0.00	1.00
D 2000	0.08	0.00	0.00	1.00	0.07	0.00	0.00	1.00
D 2001	0.09	0.00	0.00	1.00	0.07	0.00	0.00	1.00
D 2002	0.10	0.00	0.00	1.00	0.11	0.00	0.00	1.00
D 2003	0.11	0.00	0.00	1.00	0.09	0.00	0.00	1.00
D 2004	0.11	0.00	0.00	1.00	0.14	0.00	0.00	1.00
D 2005	0.12	0.00	0.00	1.00	0.14	0.00	0.00	1.00
D 2006	0.10	0.00	0.00	1.00	0.11	0.00	0.00	1.00
D 2007	0.05	0.00	0.00	1.00	0.05	0.00	0.00	1.00

Table 1.3 Regression Results: Douglas County-Papio Creek Hedonic Model

Variable	Coef.	Std. Err.	P>t
D Flood	-0.039	0.013	0.003
Ln Industry	0.016	0.002	0.000
Ln Road	0.006	0.001	0.000
Ln Water	-0.006	0.002	0.001
Ln LotSize (sqft)	0.079	0.003	0.000
Ln HouseSize (Sqft)	0.618	0.006	0.000
Age [Years]	-0.001	0.000	0.000
Fireplaces	0.067	0.002	0.000
Garage Spaces	0.081	0.002	0.000
Bathrooms	0.020	0.002	0.000
D Avg.	0.003	0.005	0.537
D Above Avg.	0.051	0.005	0.000
D 1997	-0.022	0.006	0.000
D 1998	0.021	0.006	0.000
D 1999	0.076	0.006	0.000
D 2000	0.103	0.007	0.000
D 2001	0.115	0.007	0.000
D 2002	0.146	0.007	0.000
D 2003	0.177	0.006	0.000
D 2004	0.219	0.006	0.000
D 2005	0.263	0.006	0.000
D 2006	0.257	0.005	0.000
D 2007	0.227	0.006	0.000
Constant	5.907	0.048	0.000
Obs.		22350	
F(26, 35704)		3656.22	
Prob > F		0.0000	
R^2		0.7902	
Adj R^2		0.7900	
Root MSE		0.1831	
Interpretation*		-3.9%	

** Calculated using Kennedy's (1981) equation*

Flood Insurance Costs

Based on NFIP flood insurance calculators and our sample of floodplain homes, annual flood insurance premiums among Papio-Creek properties are assumed to be 1% of the building (improved value) of properties. This also assumes that contents up to 30% of building value are also insured. Based on the average $100,000 property value of these homes in the sample this indicates that the average value of buildings/improvements would be $86,000 and that the typical cost of a flood insurance policy for such a home (covering the structure and contents) is therefore $860 per year. The present value of these insurance premiums over 30 years (and using a 7% discount rate) is $10,672 which corresponds to 11% of the total property value or 12% of the improved (home value). Alternatively, flood insurance costs over a hypothetical 30-year ownership period represent 11% of the value of Douglas-Papio Creek floodplain homes located in the original 100-year floodplain

Corresponding present values of floodplain insurance costs for homes designated to be in the new (2008-09) floodplain (based on an insurance premium calculated for non-floodplain homes) is therefore 2.8% of the value of homes (25% the cost of a regular insurance policy).

Market Values of Douglas-Papio Creek Homes

The total value of all 971 residential properties in the original Douglas-Papio Creek floodplains is $111,166,877 or $96,517,196 for improvements (buildings). The corresponding values for the 152 residential properties in the new (2009-09) Douglas-Papio Creek floodplains are $13.9 million, or $11.8 million for improvements.
The ratio of assessed values to market sales among 200 Douglas County-Papio Creek floodplain homes sold between 2002 and 2007 ranges from 80% to 91% (in 2007 based on 26 sale ratio comparisons). These observed year 2007 assessment ratios are used to convert year 2007 assessed improved values to market value improved values (i.e. assessed improved values are multiplied by 1.1).

Therefore the estimated market value for properties in all Douglas-Papio Creek floodplains (both the original and the revised 2008-09 floodplains) is $136.3 million or $118 million for improvements (buildings). Corresponding values specific to the original floodplain (971 properties) are $121.2 million and $105.2 million (improved). Corresponding values for the new 2008-09 floodplain (152 homes) are $15.1 million and $12.9 million (improvements).

Potential Flood Mitigation Benefits

1) Observed Homebuyer Preferences (Hedonic Price Estimates)

Multiplying the total assessed value of all 1,234 Douglas-Papio Creek residential floodplain properties (both the original and new floodplains) by the observed price impact of floodplain status (-3.9%) results in a total property value reduction due to the existence of the Douglas-Papio Creek floodplain of $5.3 million.

This means that if the 100-year floodplain status for all Douglas-Papio Creek floodplain homes was changed (i.e. removed) through a hypothetical upstream flood mitigation project then it is likely that these property values would increase by 3.9% (i.e. $5.3 million). This marginal price effect for an assumed 100% effective flood mitigation project (a highly optimistic scenario) can be adjusted downwards to reflect the actual impacts of flood mitigation projects. For example, if such a flood mitigation project was expected to reduce the floodplain status of only 50% of the homes in the floodplain than projected benefits would be cut in half to 1.95% (or $2.7 million). It should be noted that such benefits are captured directly by private property owners and some people in society may object to using public funds to create economic gain for private individuals, particularly when property owners either paid discounted prices for floodplain properties and/or receive other offsetting amenity benefits associated with floodplains areas (open space, wildlife, viewing, etc).

Besides being useful for cost-benefit analyses, the approach used here to estimate benefit measures from the perspective of marginal increases to property values, are useful in that they identify who specifically receives the flood mitigation benefits (in this case it is private property owners), and by how much (here, it is 3.9% of the market value of properties.) This monetary estimate could therefore be used to assign special tax assessments to individual property owners based on the relative value of flood mitigation project benefits they receive. For example, if it is assumed that floodplain property owners would be willing to paying $5.3 million in flood mitigation project costs in order for their property values to increase by the same amount (3.9%), then the proponents of flood mitigation projects should attempt to capture contributions from these private property owners. Hopefully this would reduce the tax cost burden of other residents who will receive little or no specific private benefits from flood mitigation projects.

2) Avoided Flood Insurance Costs

Multiplying the total estimated market value of improvements in the original 100-year floodplain ($105.2 million) by the observed present value cost of flood insurance (11% of structural values), generates a present value flood insurance policy cost (specific to the original pre-2008 floodplain) of $11.6 million.

This means that if the 100-year floodplain status for these 1,123 Douglas-Papio Creek properties was changed (removed) through some upstream flood mitigation project, then it is likely $11.6 million of combined flood insurance costs would be avoided. Again, these benefits accrue directly to private property owners.

It should be noted that these flood insurance premiums are only estimates and likely to be lower since many floodplain owners are likely to have obtained lower cost flood insurance policies (issues prior to official floodplain status notification from the Federal Government) and the fact that some property owners are likely to own their homes outright and hence are not legally required to have flood insurance policies. Nevertheless, this insurance cost estimate does provide a possible measure of the marginal benefits of a flood mitigation project that is 100% successful.

Since many floodplain property owners do not appear fully aware of the full costs of their flood insurance policies (in that these insurance costs are not fully capitalized into the price discounts they pay for floodplain properties), it is not very likely that these property owners would be willing to pay $11.6 million for a flood mitigation project that would reduce the present value of flood insurance costs. For this reason, the earlier hedonic based economic flood mitigation project benefits are considered more reliable for use in cost benefit analyses. Further support of the use of these potential project benefits could easily be measured through surveys of floodplain property owners in order to gauge their willingness to contribute specific monetary amounts for expected floodplain risk benefits.

Corresponding flood insurance costs for the 152 homes recently designated to be in the new (2008-2009) floodplain is only $360,000. Therefore if it was assumed that for whatever reasons Douglas County was responsible for the floodplain status of these properties, it would cost the County only $360,000 to compensate these property owners by paying their insurance premiums. Alternatively this $360,000 cost could be compared to the potential costs of proposed flood mitigation projects to determine whether it is feasible for the County to contribute to such projects.

Finally, it should be noted that there are other approaches used by policy makers to quantify flood mitigation benefits that were not evaluated by this present research. These include quantifying actual flood damage after specific flood events (i.e. historical flood data), and/or the determination of the value of first-floor housing structures (and home contents) that would be potentially damaged during 100-year flood events. This issue is discussed further in the Policy and Implications section.

Summary and Policy Implications

This research has demonstrated a methodology to accurately measure flood mitigation benefits using empirical real estate transaction data. The observed price differences between floodplain and non-floodplain homes in Douglas County (3.9%) could potentially be used by the PMNRD and/or County governments or others in negotiating fair market prices to pay for floodplain homes as part of their floodway purchase program. These statistics may also be taken into consideration by county tax assessors when valuing floodplain residential properties.

Alternatively this floodplain impact measure can be used as a reliable measure of avoided flood damage (i.e. an economic benefit of particular flood mitigation projects). In this case it was shown that if a future flood mitigation project was able to remove the 100-year floodplain status for all of the Douglas-Papio Creek floodplain properties (which is a highly optimistic and perhaps impossible and/or expensive outcome), then it is likely that these property values would increase by 3.9% (i.e. $5.3 million). Similar benefits associated with mitigation projects that reduce the floodplain status for fewer homes can also be estimated using the data and analyses contained in this report. This information is expected to be useful for Douglas County when evaluating the economic feasibility of participating in future flood mitigation projects associated with the Papio Creeks.

If flood insurance costs were considered a more relevant measure of potential flood mitigation benefits, then flood mitigation project costs should be compared to $11.9 million for all floodplain properties or $360,000 for only properties in the new floodplains.

A summary of potential estimated benefits of future (hypothetical) Douglas-Papio Creek flood mitigation projects requires multiplying property value impacts and/or insurance costs by the estimated value of properties expected to be removed from the floodplain (which would hopefully be quantified by the 'feasibility studies' of particular flood mitigation projects). A full range of these potential benefits associated with hypothetical flood mitigation projects that remove between 10% and 100% of homes from the Douglas-Papio Creek floodplain are summarized in Table 1.4. Depending on the likely effectiveness of flood mitigation projects and the types of benefits considered, the value of future (hypothetical) Douglas-Papio Creek flood mitigation projects ranges from $36,000 (only 10% of homes removed from the floodplains and considering only new insurance costs to homes placed in the floodplain in 2008-09) to $11.9 Million (100% of homes removed from the floodplains and considering all avoided insurance costs).

Table 1.4. Potential Estimated Benefits of Douglas-Papio Flood Mitigation Projects

	Homes Potentially Removed From the 100-Year Floodplain (from a hypothetical flood mitigation project)			
	10%	***25%***	***50%***	***100%***
A) Property Value Increases (hedonic estimates, all floodplain homes)		$ 1.3 million	$ 2.7 million	$ 5.3 million
B) Avoided Insurance Costs (All Floodplains homes)		$ 2.9 million	$ 6.0 million	$11.9 million
C) Avoided Insurance Costs (2008-09 Floodplain home additions only)	$36,000	$90,000	$180,000	$360,000

** Note these potential benefits should not be combined as this would be a form of double (or even triple) counting of the same benefits.*

A possible limitation in using this floodplain impact and benefit valuation research is that two other key property types have not been considered. These include commercial property which ***may*** be as much or more valuable than residential property within Douglas County floodplains, and undeveloped property, which if removed from the floodplain could have a significantly higher and best use.

It is therefore proposed that these two missing classes of floodplain properties be included on a list of recommended future research. But it should also be noted that if commercial property values are two, three or even four times the value of residential property values in the Douglas-Papio Creek floodplains, this does not necessarily mean that the marginal benefits of removing commercial floodplains from the properties will automatically generate flood mitigation benefits that are this magnitude or larger than observed with residential properties. This is due to various differences between structural characteristics of commercial and residential properties. For example, many commercial properties are multi-storied meaning that flood risk is only associated with ground floor portions of the structures. It is therefore highly recommended that future research be conducted on the impact of floodplains on commercial properties in the Douglas-Papio Creek areas. If and when this does occur it will be very important to identify the level of potential flood mitigation efforts captured by specific commercial property owners.

This research has generated transparent and replicable research that should in the future be useful to Douglas County or other local government entities for the task of evaluating the benefits and economic feasibility of flood mitigation projects. In particular the data provided here can be used to evaluate different types of economic benefits associated with flood mitigation projects that directly impact Douglas County. This information can also be used to determine how much individual property owners should contribute to flood mitigation projects, and to taxpayers in deciding whether or not they support particular flood mitigation projects.

Proposed Follow-up Studies

1) Comparable sales-based appraisal analyses.

It would be prudent to re-estimate these impacts using an alternative approach, namely the use of traditional appraisal-based comparable sales analyses where floodplain homes are compared directly to two or three nearby comparable sales not in the floodplain.

2) Improving flood insurance cost estimates.

More accurate estimates are needed based on home specific characteristics. This would likely require site inspections of individual homes and/or surveys of homeowners.

3) Surveys of floodplain property owners.

It would be interesting to determine the percentage of homebuyers who knew about the floodplain status of their homes when they were purchased, their understanding of the financial implications (required flood insurance costs), and their perception concerning flood risk and the pros and cons of living in the floodplain.

4**) Estimating the impact of floodplain status of undeveloped land.**

It may likely be that that floodplain status has a larger impact on undeveloped residential and/or commercial lots than what was observed for developed properties. It is expected that the hedonic methodologies used in this present study can be adapted to a lot-level analyses with recently collected lot sales data in Douglas County. This analysis is planned by the UNO research team in the coming months (a supplemental project for which no additional funding is needed or sought). This is considered critical to estimating the total potential benefits of proposed floodplain mitigation benefits.

5) Estimating the impact of floodplain status on commercial properties.

It may be that commercial property values in the Douglas-Papio floodplain may be substantially (up to four times) higher than residential values. In addition to evaluating the accuracy of assessed tax values for estimating commercial market values in these floodplains, it will be necessary to quantify how floodplain designations impact commercial property values, and it is also necessary to estimate the present value of flood insurance premiums for commercial properties.

6) Replication of the entire research effort in Sarpy and Washington Counties.

It would be advisable to replicate these completed and proposed research items studies in Sarpy and Washington County. The acreage of Douglas-Papio Creek floodplains is around 7,200 acres versus around 6,200 acres for the Sarpy-Papio Creek floodplains.

Lake Views, Access, and Residential Property Values

Background and Objectives

In the last decade, several man-made lakes have been constructed in the Omaha area for the purposes of flood control, recreation, and to create amenities for adjacent and/or nearby residential housing. Additional lake construction is now actively being planned and promoted for these same purposes, as well as for stormwater management, primarily by the Papio Missouri Natural Resource District (PMNRD).

The intent of this present study component is to evaluate how different types of man-made lakes in the Omaha area impact residential property values. The goal is to quantify premiums that homebuyers are willing to pay for both lake views and access, and to determine how much of these premiums are captured by the private sector (i.e. residential housing developers) through the sale of residential lots that have views and/or good access to man-made lakes. Hopefully this information will be used in the future to ensure that private developers make adequate (fair market) contributions to future lake construction efforts which they will benefit from. It is assumed that such private sector contributions are only appropriate in cases where developers sell, trade, or contribute land or financial assistance to lake construction that is adjacent to land which they own.

This study relies on four interrelated approaches. First, hedonic price modeling is used to quantify the determinants of residential housing sales at four different lakes over the 2000 to 2007 time period. The lakes include: Zorinsky, Standing Bear, Candlewood, and Walnut Creek. The validity of the use of this hedonic valuation approach for valuing lake views has already been established as preliminary research results that focused on only two of these lakes (Zorinsky and Standing Bear) have recently been accepted for publication in the summer, 2008 issue of the peer reviewed The Appraisal Journal.

Second, comparisons are made between the sale prices of vacant lots with and without views in order to determine if original landowners and/or developers capture lake amenity premiums at the time lakes are constructed or alternatively, whether lake view premiums develop gradually over time and hence are captured by subsequent homeowners. Third, comparisons are made between the prices of non-view lots with close access to lakes (within 2000 feet), and the prices of non-view lots that are further away (more than 2000 feet away but within ½ mile) to quantify access values.

Fourth, detailed comparisons of lot prices both within the Elk Ridge subdivision on the western shore of the Dam Site 13 Lake which is the most recent lake constructed in the Omaha area, and the first 'Public-Private Partnership' between the PMNRD and a residential housing developer. Since not enough homes within this sub-division have yet sold, it was not possible to estimate a conventional hedonic valuation model at this lake. Instead, several alternative comparisons are made between sold lot prices within and nearby the subdivision in order to estimate both view and access premiums that are likely to be captured over time by the developer. View premiums are based on observed differences between view and non-view lot prices within the subdivision.

In contrast, access premiums are based on observed differences between non-view lots in Elk Ridge and in several nearby subdivisions that do not have as good access to the Dam Site 13 Lake. View and access premiums are then used along with existing lot maps for the subdivision, to estimate total premium values be captured by the developer.

All of these analyses combined, are expected to be useful for demonstrating the economic value that Omaha area residents place on lake amenities, and to estimate the economic benefits generated by the construction of different types of new lakes in the Omaha area in the coming years. As well, the results of this study might be a useful tool for negotiating 'fair-market' financial contributions which real estate developers (who build single-family residences adjacent to and/or nearby future lakes) should make to the future lake construction efforts.

Background Information on the Five Study Lakes

The location of all five of the lakes evaluated by this study are shown in Figure 2.1. Standing Bear Lake was constructed by the USACE in 1977 and encompasses 135 acres.

It contains an extensive 396 acres of public parkland and buffers between the lake and nearby residences. Lake Zorinsky, completed in 1993 by the U.S. Army Corps of Engineers (USACE), covers 255 acres and is surrounded by private residential housing along with some public use areas and public buffers.

Candlewood Lake was constructed in 1978 entirely by a private developer after the USACE determined that it was not economically feasible for the purposes of flood control. It is only 34 acres in size and is completely surrounded by private residences (98 homes) and contains no public access of buffers. Water quality in the lake is marginal. In stark contrast is Walnut Creek Lake, which is 105 acres and was constructed in 1999 with funds from the PMNRD, the Nebraska Natural Resource Commission, and the Nebraska Game and Parks Commission. It contains very extensive (450 acres) public recreation areas and land buffers around the lake and so far appears to have good water quality.

The Dam Site 13 Lake was constructed in 2005 and 2006 by the PMNRD and with financial contributions from a private developer. The developer purchased the entire land parcel where the lake, parks and residential developments are for $53,000 per acre and then sold to the PMNRD all the land needed for the dam and lake as well as adjacent land on the western and southern shore for the same price (on a per acre basis). The developer retained control of the western shore of the lake as well as a small land tract on the eastern shore, and contributed $1 million in cash and $600,000 in future payments to help offset the cost of the dam and lake construction (Deed of Trust, PMNRD, 2006). The remaining project costs of around $6.4 million were met by PMNRD and the majority of these expenses were associated within land procurement and dam construction costs. The present value of dam maintenance costs over time (which will be the responsibility of the PMNRD) have not been explicitly stated.

Much of the adjacent land on the southern shore of the Dam Site 13 Lake has been turned over to the City of Omaha for a public park (‘Memorial Park of the West’), and this park area is connected to the western fringe of the lake via a public walking trail (See figure 2.3). Although none of the residential lots on the western shore that are being developed have 100% exclusive access to the lake, their boundaries are very close to the lake and there are no visibly planned public parking or access points located on the western or northern shores of the lake (i.e. within the Elk Ridge housing development). Therefore, lake access for the majority of the public will have to be through the southern part of the lake. Alternatively, almost half of the lake appears to have been captured for private use. The developer also owns a small commercially-zoned area on the western shore of the lake that is next to a privately-owned industrial land use.

Finally, the PMNRD states that the lake will reduce runoff from the 2-square mile watershed by 90% in a 500-year flood event but will not reduce any of the main-stem Papio 100-year floodplain (Personal Communication March 4, 2008, Paul Woodward, PMNRD).

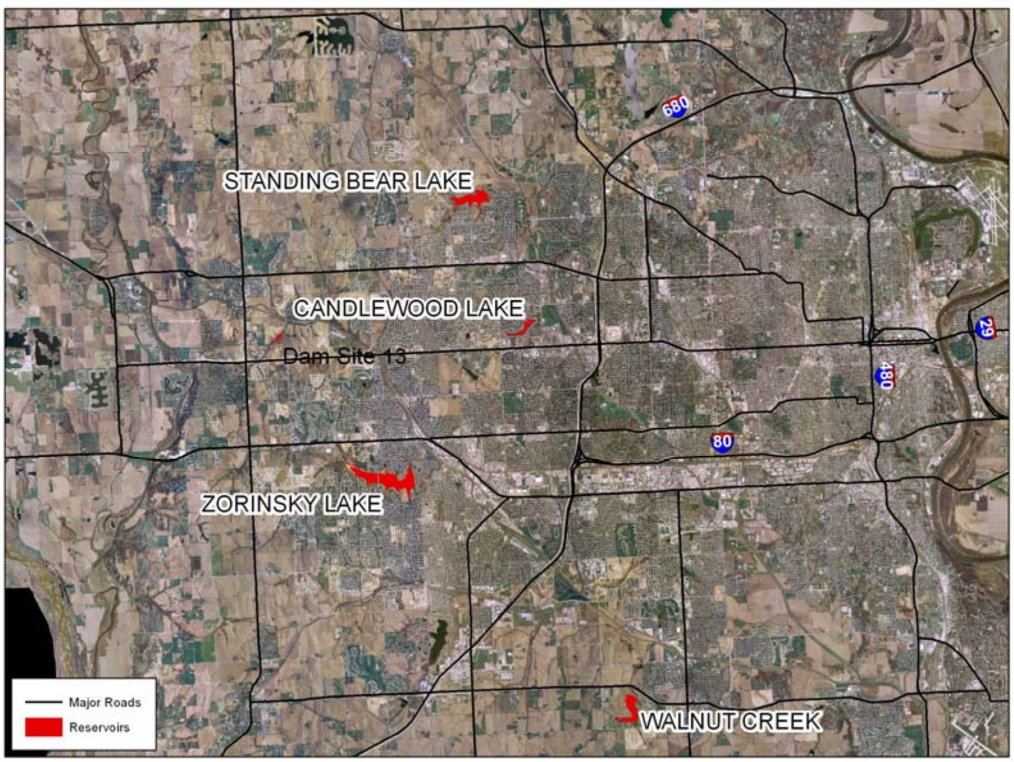


Figure 2.1. Location of the Five Lakes Evaluated

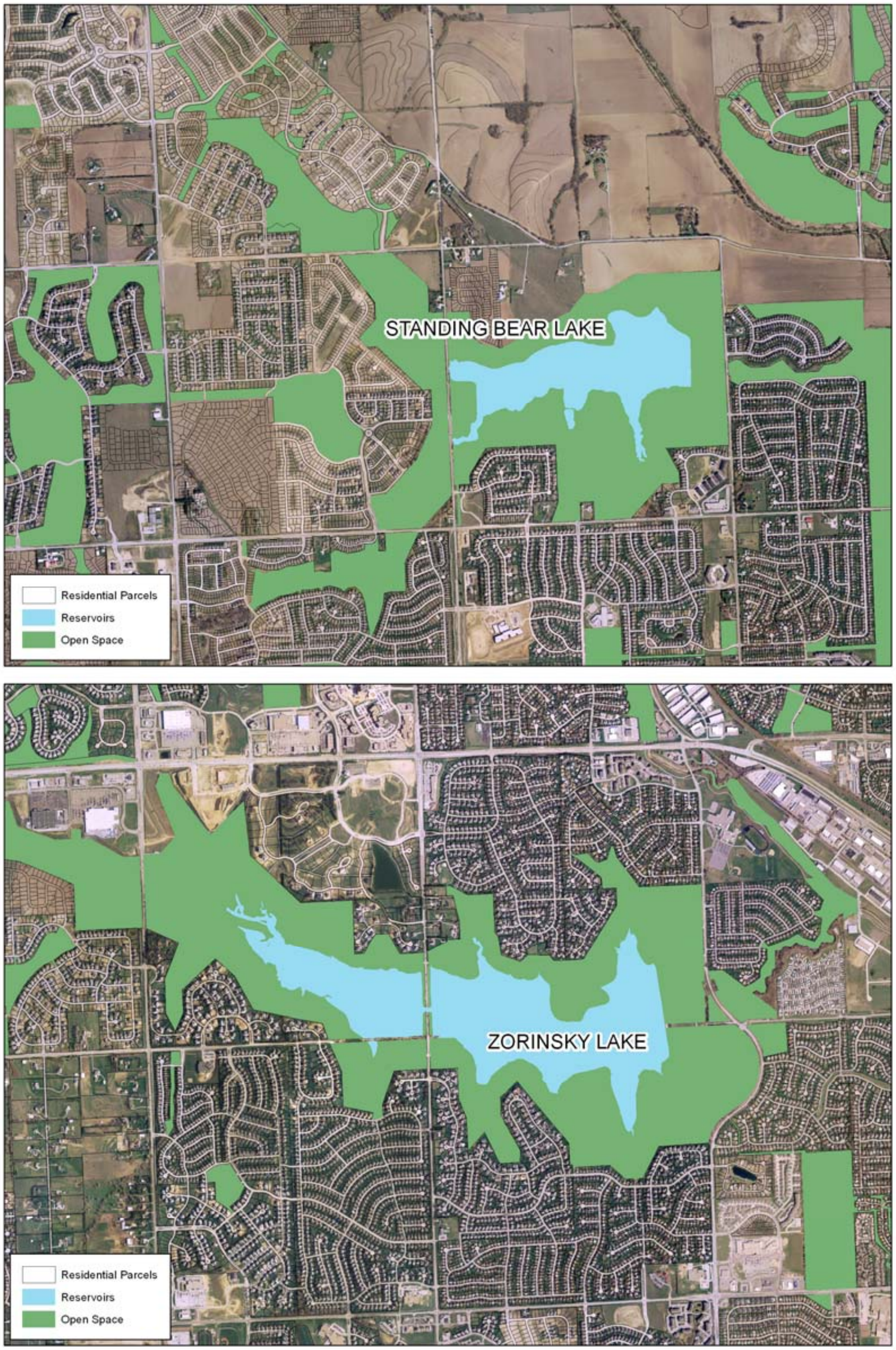


Figure 2.2 Land Uses Surrounding Standing Bear and Zorinsky

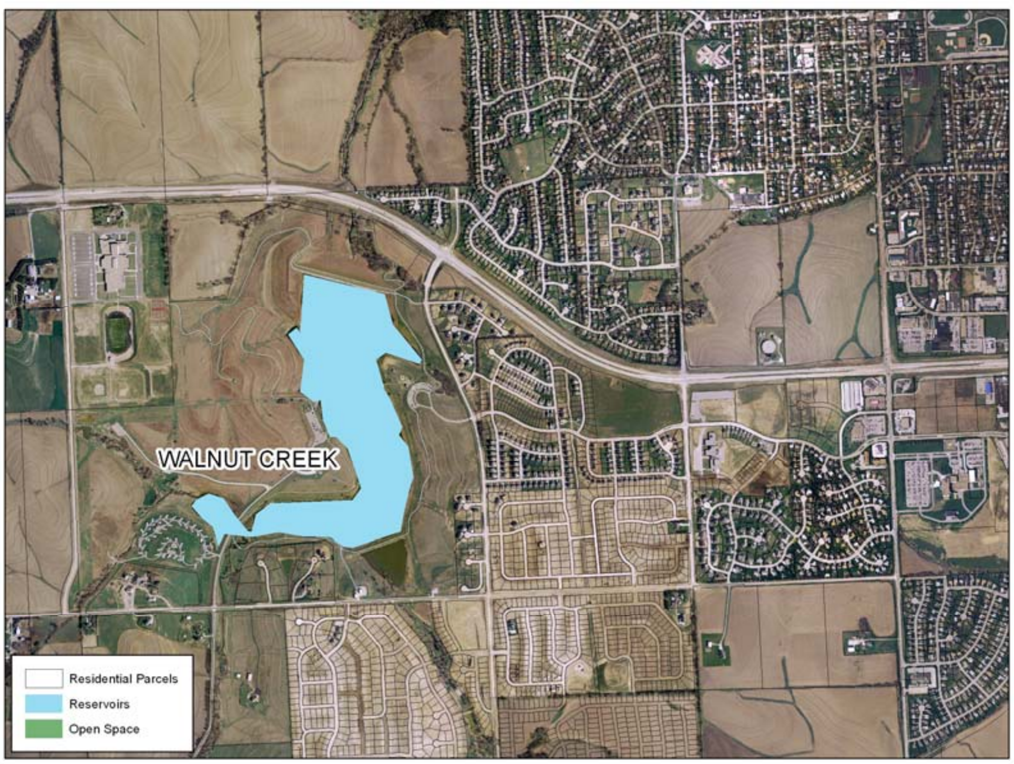


Figure 2.3. Land Uses Surrounding Candlewood and Walnut Creek

Figure 2.4. Land Uses Surrounding Dam Site 13
Source: http://www.elkridgelake.com/Elk%20Ridge/Images/newERdevplan.pdf

Methods and Procedures

Hedonic Price Models for Four Lakes

Four separate hedonic valuation models are estimated to quantify the factors influencing single-family housing sale prices over the 2000 to 2007 time period at Zorinsky, Standing Bear, Candlewood, and Walnut Creek. The specifications of these hedonic models are very similar to the floodplain hedonic model described in the previous section of this report. Sale prices (represented as natural logs), are regressed against structural, neighborhood characteristics, and the lake view status of individual homes.

The sale price and structural characteristics of homes were obtained from both the multiple listing service (MLS) and Douglas County property records, and referenced to a parcel-level GIS database. The resulting 2,188 sale transactions represent all sold homes within one half mile miles of the Zorinsky, Standing Bear and Candlewood lakes and within 1 mile of the Walnut Creek Lake. The additional half mile study area was needed at Walnut Creek due to the large public buffer areas around the lake and the infrequency of residential sales that have occurred around the lake.

Structural variables in the hedonic models include house and lot size, house age, presence of a walkout basement, number of fireplaces and garage stalls, and house style. Dummy variables representing the year a home was sold are also included to account for housing price appreciation over the study period. Condition is accounted for simply as a dummy variable equal to 1 if the home was classified as in average condition by the Douglas county assessors office (this variable was not available for Walnut Creek Lake in Sarpy County). The classification of whether a home has a lake view is based on GIS viewshed analyses in conjunction with drive-by inspections. Due to the use of the log-linear specification with the lake view variable, the marginal implicit price of views can be interpreted directly from the model coefficient and measures the percentage change in housing price due to the existence of a view. However, a more precise interpretation of this variable was calculated by using the Kennedy (1981) equation.

Comparative Analyses of Lot Sales (Zorinsky and Standing Bear)

Differences between the sale prices of undeveloped lots with and without views were evaluated at both Zorinsky and Standing Bear lakes in order to identify the extent of view premiums that were captured by developers (or homebuilders/buyers) at the time the lakes were first constructed. Such comparisons are made on a per square foot basis in order to control for varying lot sizes. Again, these comparisons were not possible at Candlewood Lake due to the infrequency of locatable lot sales with view of the lake (it appears that many lots were built by the developers themselves and not sold on the open market. Similarly, lot comparisons were not made at Walnut Creek Lake because not enough lot sales could be located (it appears that many multiple-lot sales were made directly to builders). Lot sales data for the remaining two lakes (Standing Bear and Zorinsky) was collected by performing backward deed searches for all of the residential housing lots within one-half mile of the lakes. Again, the GIS viewshed analyses were used to classify whether or not particular lots had lake views.

Similar comparative lot sale price analyses at Standing Bear and Zorinsky were made in order to capture potential **access** premiums. This involved comparing sold lot prices of lots (again on a square foot basis) of non-view lots within 2000 feet of lakes versus non-view lots that were between 2000 feet and one-half mile away from each lake.

Dam Site 13 (Elk Ridge) Analyses

The first methodological approach for the analysis of the Dam Site 13 Lake development was to create a GIS database of the lake site and all of the plotted residential parcels around the lake. This included those parcels immediately adjacent to the lake (within the Elk Ridge subdivision which is the focus of the analysis) and parcels in three nearby subdivisions (Elk Valley, Five Fountains, and Silverleaf). A detailed deed search was then conducted to identify the sale prices of all lots within each of these four subdivisions up to February 1, 2008. The asking prices and view status of all Elk Ridge subdivision lots were also obtained directly from an employee of the Elk Ridge Development. Finally, the view status of all lots was determined using both GIS viewshed analyses and manual drive-by inspections of all lots.

Lot view premiums were estimated by calculating the differences between view and non-view lot sale prices *within* the subdivision again, on a dollar per square foot basis in order to control for varying lot sizes. These view premiums were then multiplied by the total area (square feet) of actual and potential view lots within the development. Potential view lots involve the substitution of five residential lots (of average size) in the place of the existing assisted living building on the northwest side of the lake, and four more potential residential lots (again of average size), substituted in the place of the planned condos and office units on the east side of the lake. Since the assisted living and condo/office lots are likely to have relatively higher values than conventional residential lots, the resulting premium values associated with these substitutions are considered to generate conservative (lower bound) premium estimates.

Lake access premiums for non-view lots were estimated by calculating the difference between non-view lot prices *within* the Elk Ridge subdivision with non-view lot sale prices *outside* the subdivision (again on a dollar per square foot basis in order to control for varying lot sizes). The three nearby subdivisions used for the comparisons were Elk Valley, Five Fountains, and Silverleaf and all were within one-half to one-quarter mile from Elk Ridge (see Figure 2.10). Lot sales at these subdivisions have been recent except for Elk Valley, which was developed 2 years prior to Elk Ridge. Only non-view lots were used for these comparisons so as to not 'double count' view and access values.

It is hypothesized that access premiums exist at Elk Ridge since it's residents will be able to walk to the lake in contrast to the residents of the other subdivisions will need to cross busy streets to gain lake/park access and/or will only be able to park in the extreme southern part of the Omaha City Park (Memorial Park West) since there does not appear to be any public parking on the northern or western parts of the Lake.

Resulting access premiums are then multiplied by the total (aggregate) square footage of all non-view lots within Elk Ridge to generate an estimate of the total premium value associated with non-view access.

Finally, lake access premiums for view lots were calculated by subtracting the average price premium calculated for view lots from the average prices of view lots, and then multiplying this value by the percentage-based access premium associated with non-view lots. Access premiums for view lots are then multiplied by the total square footage of actual and potential view lots.

The combined (view and access) premiums expected to be captured by the Elk Ridge developers were then discounted over a five-year period under the assumption that no lot sales (and premiums) occurred in year one and that the remaining lot sales and premium captures are spread out evenly over the remaining four years. This five-year project cycle is based on the observations of lot developments at other Omaha lake sites.

Results

Hedonic Price Estimates

Table 2.1 contains a summary of the available housing sale transaction data for view and non-view properties within a half-mile of Standing Bear, Zorinsky and Candlewood Lakes and within one mile of Walnut Creek Lake, over the 2000 to mid 2007 time period. Actual sales by view status at each of the four lakes are shown in Figures 2.5 and 2.6.

Table 2.1. Sale Data for View and Non-View Properties (Houses and lots) by Lake

	Sales		Time Frame	Median Prices		Mean Size Finished (ft^2)	
	View	Non-View		View	Non-View	View	Non-View
Standing Bear	35	446	2000 – 2006	203,500	167,225	2,219	2,011
Zorinsky	62	755	2000 – 2006	331,250	184,900	3,874	2,442
Candlewood	15	295	2000 – 2007	330000	198000	4042	2905
Walnut Creek	26	233	2000 - 2007	307253	163500	2826	2137

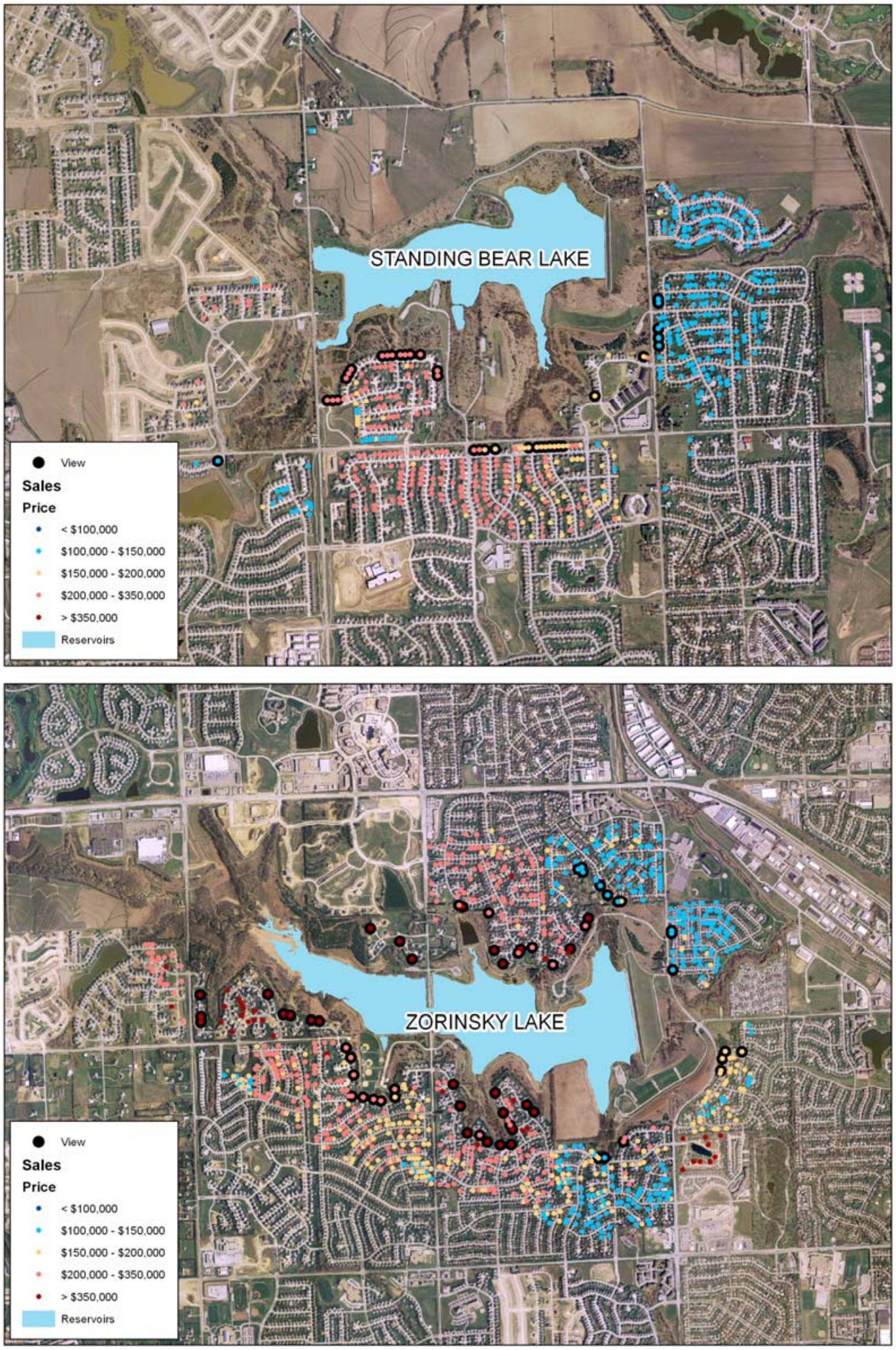


Figure 2.5. Sold Homes with Direct Views of Standing Bear Lake and Zorinsky

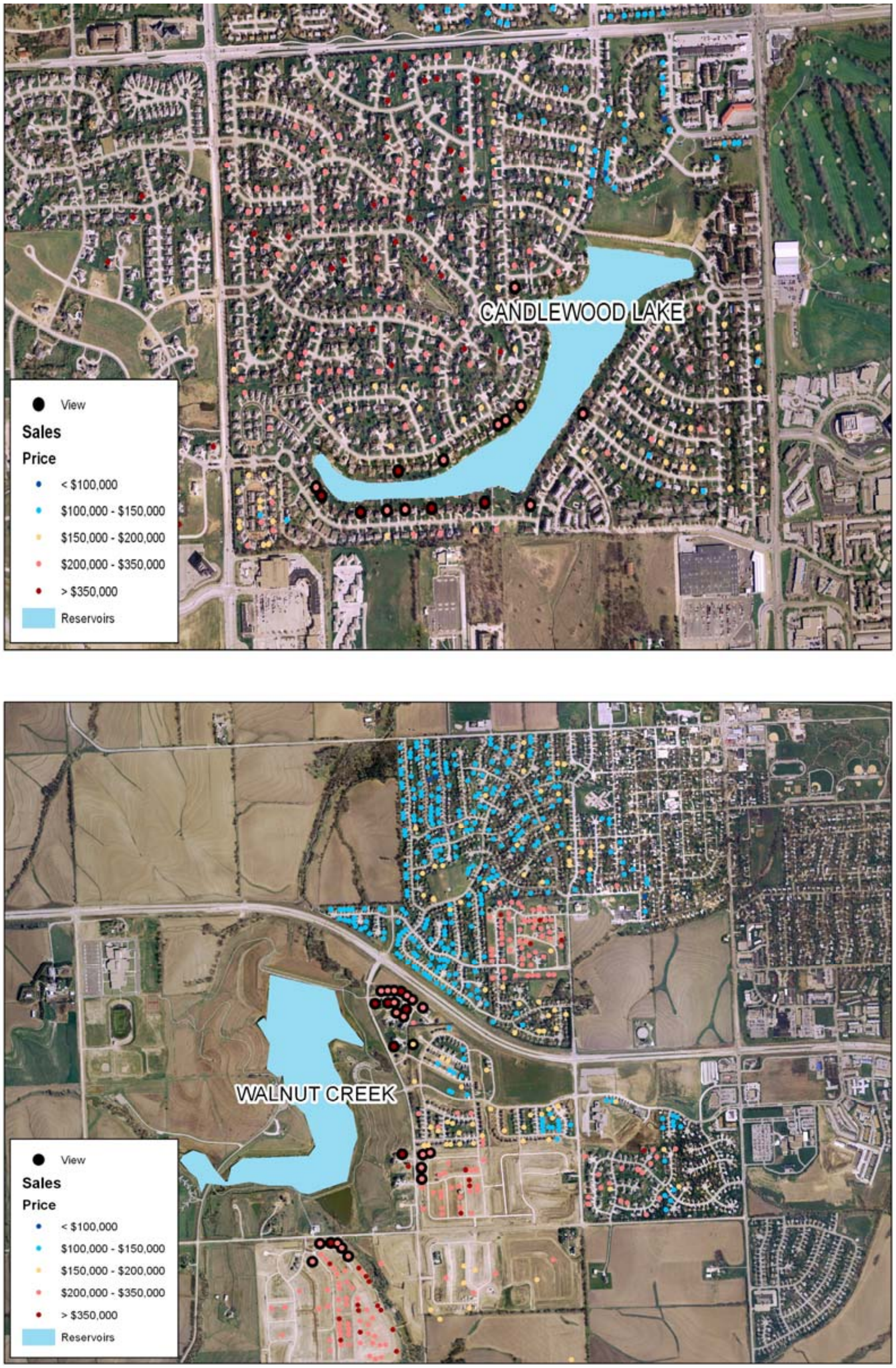


Figure 2.6. Sold Homes with Direct Views of Candlewood and Walnut Creak Lake

The hedonic valuation regression results measuring the marginal impacts of lake views and other housing characteristics (considered jointly) on housing prices at each of the four lakes are summarized in Table 2.2 (and described in greater detail in Tables 2.3 and 2.4). All four models have relatively high adjusted R^2 values of .92, meaning that 92% of the variation in housing prices is explained by the models. As well, the direction and magnitude of all of the model coefficients are as expected with most being statistically significant at the 1% level.

Of particular interest is the 'D View' variable measuring whether or not a home has a direct view of the lake. The coefficient can be interpreted as the marginal impact of a view on the sale price of a home holding all other factors constant.[1] This translates to 8.3% at Standing Bear, 7.5% at Zorinsky, 17.9% at Candlewood and 6.5% at Walnut Creek (Table 2.2). In dollar terms, this corresponds to an impact of $19,851 for an average-priced home at Standing Bear versus $44,589 at Zorinsky, $61,258 at Candlewood, and $20,420 at Walnut Creek.

Extrapolating these values to all the existing and potential homes with views of these lakes generates $15.4 million in premium value at Zorinsky versus $3.2 million at Standing Bear, $6 Million at Candlewood and $2.1 Million at Walnut Creek. This corresponds to an additional $26.7 million in increased property values.

Table 2.2. A Summary of the Hedonic Price Models and View Premiums by Lake

	R^2	Hedonic View Impact (Price Premium)		
		%	$/House(Avg.)	Total Value
Standing Bear	.92	8.3%	$19,851	$3.2 Million
Zorinsky	.91	7.5%	$44,589	$15.4 Million
Candlewood	.92	17.9%	$61,258	$6 Million
Walnut Creek	.92	6.5	$20,429	$2.1 Million

[1].When estimating a semi-log model a direct interpretation of the dummy variable coefficient as a percentage of sale price is not valid. Therefore, the equation presented by Kennedy is used to adjust the coefficients for interpretation: $\hat{g} = e(\hat{c} - (1/2)V(\hat{c})) - 1$ where c is the regression coefficient and V(c) is the variance of the coefficient or the standard error squared Kennedy (1981)

Table 2.3. Hedonic Regression Results: Standing Bear & Zorinsky

	Standing Bear			Zorinsky		
Variable	Coef.	Std. E.	P>t	Coef.	Std. E.	P>t
Constant	7.621	0.210	0.000	5.218	0.190	0.000
Structural Variables						
Ln Lot Size	0.147	0.020	0.000	0.246	0.019	0.000
Ln Sq. Ft.	0.364	0.023	0.000	0.563	0.021	0.000
Age	-0.008	0.001	0.000	-0.011	0.001	0.000
D Walk Base.	0.037	0.010	0.000	0.034	0.010	0.001
Fireplaces	0.028	0.010	0.005	0.059	0.009	0.000
Garage Stalls	0.071	0.009	0.000	0.098	0.011	0.000
D Avg_Cond	-0.007	0.012	0.531	-0.026	0.012	0.028
D 1.5 Story	0.429	0.046	0.000	0.104	0.026	0.000
D 2 Story	0.202	0.019	0.000	0.020	0.014	0.154
D Split	-0.021	0.012	0.085	-0.009	0.014	0.505
D Ranch	0.168	0.016	0.000	0.060	0.016	0.000
Time Trend Variables						
D 2001	0.022	0.014	0.129	0.054	0.016	0.001
D 2002	0.041	0.015	0.007	0.079	0.016	0.000
D 2003	0.048	0.015	0.002	0.114	0.015	0.000
D 2004	0.098	0.015	0.000	0.160	0.016	0.000
D 2005	0.119	0.015	0.000	0.190	0.016	0.000
D 2006	0.109	0.020	0.000	0.199	0.024	0.000
D View*	0.080	0.016	0.000	0.073	0.018	0.000
Obs.	481 (View = 35)			817 (View = 62)		
F	322.48			433.85		
p>F	0.000			0.000		
R2	0.9263			0.9073		
Adj. R2	0.9234			0.9052		
Root MSE	0.08421			0.11754		

** Note: These dummy variable coefficients cannot be interpreted directly as percentages (unlike continuous variables) using Kennedy's (1981) equation the marginal implicit values are 8.3% and 7.6% respectively.*

Table 2.4. Detailed Hedonic Regression Results: Candlewood & Walnut Creek

	Candlewood			Walnut Creek		
Variable	Coef.	Std. E.	P>t	Coef.	Std. E.	P>t
Constant	6.177	0.237	0.000	5.392	0.247	0.000
Structural Variables						
Ln Lot Size	0.099	0.020	0.000	0.169	0.022	0.000
Ln Sq. Ft.	0.637	0.036	0.000	0.639	0.025	0.000
Age	-0.013	0.001	0.000	-0.008	0.001	0.000
D Walk Base.	0.009	0.021	0.681	0.047	0.013	0.000
Fireplaces	0.051	0.016	0.001	-0.011	0.015	0.462
Garage Stalls	0.091	0.021	0.000	0.114	0.012	0.000
D Avg_Cond	-0.018	0.028	0.519	-	-	-
D 1.5 Story	0.068	0.030	0.022	0.104	0.034	0.002
D 2 Story	0.031	0.025	0.218	0.039	0.018	0.027
D Split	-0.068	0.029	0.021	-0.052	0.015	0.000
D Ranch	0.010	0.027	0.717	0.039	0.019	0.037
Time Trend Variables						
D 2001	-0.011	0.030	0.720	-0.023	0.025	0.360
D 2002	0.068	0.029	0.019	0.003	0.023	0.908
D 2003	0.079	0.030	0.010	0.036	0.020	0.081
D 2004	0.144	0.030	0.000	0.085	0.020	0.000
D 2005	0.194	0.031	0.000	0.151	0.020	0.000
D 2006	0.188	0.030	0.000	0.139	0.019	0.000
D 2007	0.176	0.033	0.000	0.105	0.023	0.000
D View/ Frontage*	0.166	0.042	0.000	0.063	0.026	0.017
Obs.	310 (View =15)			259(View =26)		
F	166.72			161.79		
p>F	0.000			0.000		
R2	0.9161			0.9239		
Adj. R2	0.9106			0.9182		
Root MSE	0.13502			0.11834		

** Note: These dummy variable coefficients cannot be interpreted directly as percentages (unlike continuous variables) using Kennedy's (1981) equation the marginal implicit values are 17.9% and 6.45% respectively.*

Lot Sale Comparisons to Quantify View and Access Values

At Standing Bear, view lots sold for 18.8% ($13,598) more than non-view lots. This value is more than twice as large as view premiums estimated by the hedonic approach which illustrates an interesting and somewhat surprising situation: It would appear that view premiums at Standing Bear appear to have declined over time. Alternatively, when Standing Bear Lake was developed, developers were able to capture a premium for lake view lots that is higher (in percentage terms) than subsequently observed lake view premiums determined though hedonic valuation models (and housing sale transactions).

At Zorinsky, developers captured a 5.7% premium ($3,507) when the lots were initially sold and over time this premium increased slightly to 7.5%.

The access premiums observed for lot sales at Standing Bear Lake is 11% and a similar 12% at Zorinsky. But there are several potential problems with the approaches used here to value access premiums at each of these lakes. In particular, simple distance measurements (lots less than 2000 feet from the lake but not being frontage or view lots versus lots that are more than 2000 feet from the lake) are not likely to perfectly measure the quality of lake access. Therefore, it is proposed that a future study measure the distances from individual lot sales to trail access points, and/or conduct comparisons of lots within particular subdivisions that are deemed to classified to have excellent versus poor access to lake recreation areas.

Lake View and Access Premiums at Dam Site 13

The platted parcels for the Elk Ridge subdivision classified by property types (‘villas’ without views, ‘estates’ with views, and frontage lots with views) are shown in Figure 2.7 and summarized in Table 2.4. The location of the five potential lake frontage lots in the northwestern part of the lake (where an assisted living facility is now located) and four potential frontage lots on the western shore of the lake (where a series of condos and commercial structures are located) can be seen in the earlier Figure 2.4.

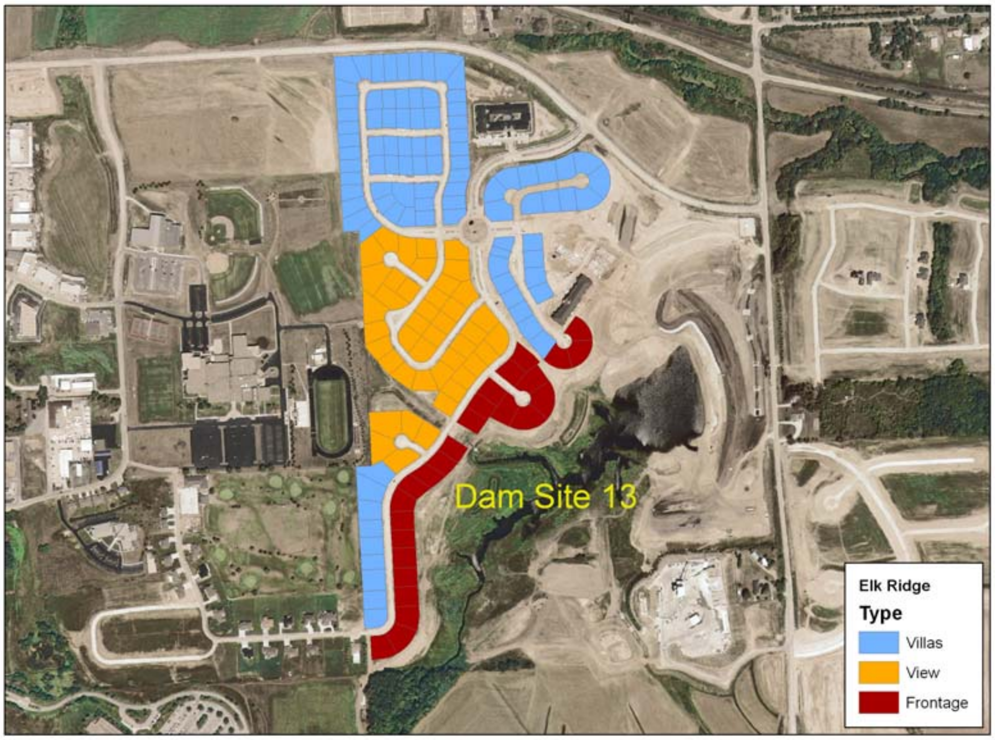


Figure 2.7. Residential Lots in the Elk Ridge Subdivision

Table 2.5. Summary Statistics of All Elk Ridge (Dam Site 13) Lots

Lot Type	**N**	**Size**			
		Mean	***Min***	***Max***	***Total***
'Villas' (non-view)	92	14,033	9,583	28,314	1,291,119
View ('Estates')	43	17,079	13,068	30,056	734,423
Frontage	25	19,096	16,988	24,829	572,898*
View/Frontage Lots (combined)	68	17,821	13,068	30,056	1,307,325*

** Nine average frontage size lots added to square foot total to account for potential lots in the areas of he assisted living care (northwest shore) and the condos (western shore)*

Figure 2.8 shows the location of the Elk Ridge parcels that have sold as of February 1, 2008. This includes 14 'Villa' (non-view) lots and four 'Estate' (view) lots. While none of the frontage view lots have sold as of February 1, it should be noted that the asking prices (on a square foot basis) are 36% higher than non-frontage view lots. And, according to a representative of the developer, they are planning to have frontage view lots be made part of a '2009 Street of Dreams' promotion.

The asking prices of all lots in the Elk Ridge subdivision are shown in Figure 2.9 and direct comparisons of the asking and sold lot prices from 2005 to February 1, 2008 are summarized in Table 2.6. Somewhat surprisingly, all of the lots have been selling for their asking prices and some have actually sold for amounts slightly above their asking prices. This demonstrates that the developer of Dam Site 13 was able to accurately estimate buyer premiums for views and access.

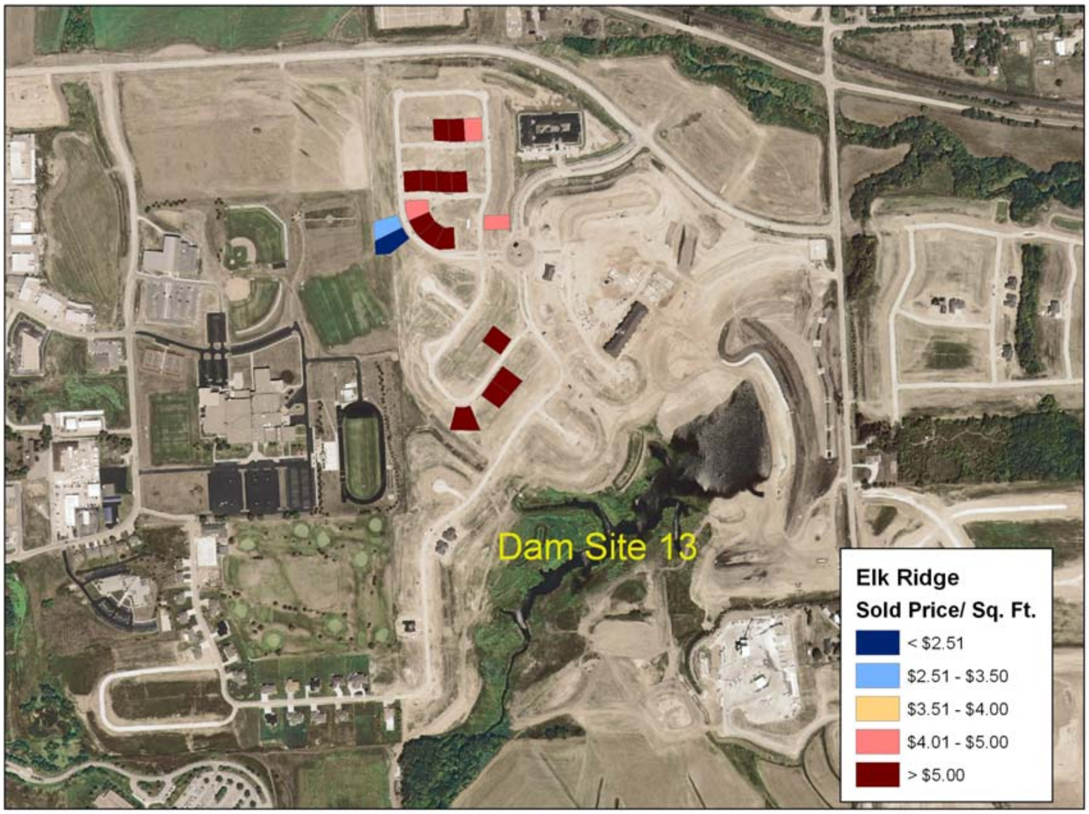


Figure 2.8. The Location of Sold Residential Lots in the Elk Ridge Subdivision

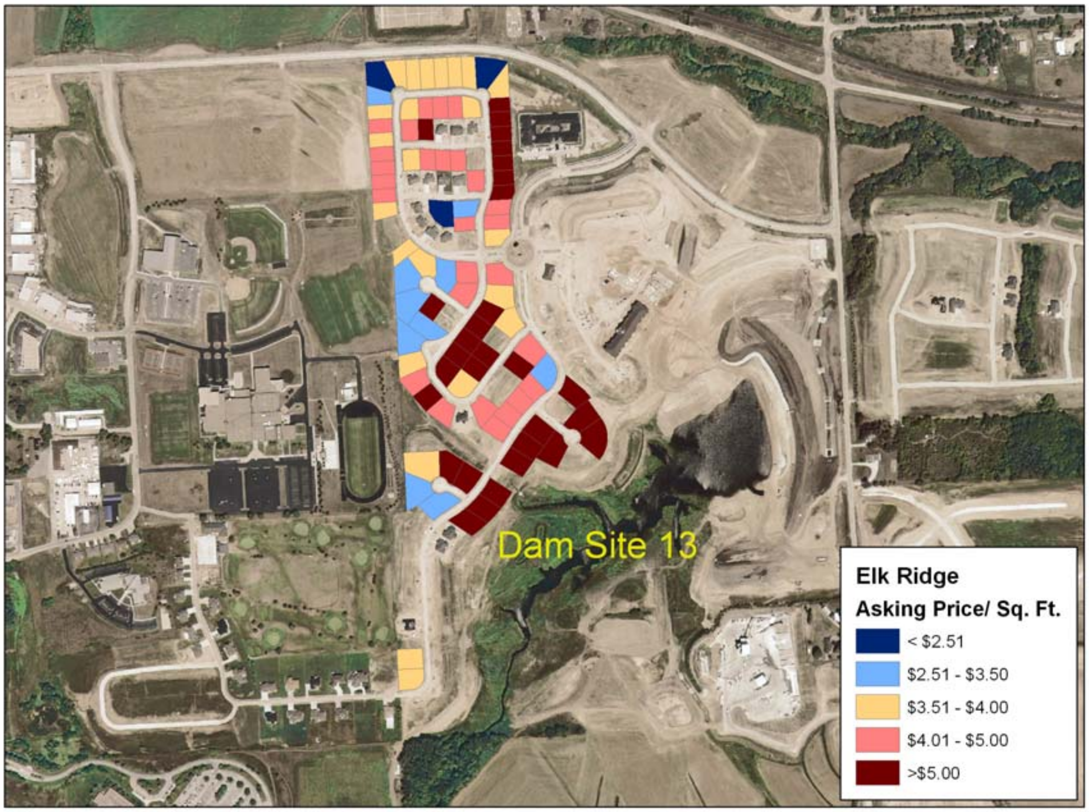


Figure 2.9. Asking Prices of Elk Ridge Lots

Table 2.6. Asking and Selling Prices of Elk Ridge Lots (2005 to February, 2008)

	Villas (Non-Views)	Views	Frontage	All
Asking Price Lot	$50,217 (46)	$74,486 (37)	$128,500 (10)	$68,290 (93)
Sold Price Lot	$54,954 (14)	$90,000 (4)	(0)	$62,742 (18)
Sold Price House	$458,414 (6)	(0)	(0)	$458,414 (6)
Asking Price/ Sqft	$4.14 (46)	$4.45 (37)	$6.73 (10)	$4.55 (93)
Sold Price Lot/ Sqft	$4.71 (14)	$5.96 (4)	(0)	$4.99 (18)

View premiums at Elk Ridge based on comparisons of the sold lot prices (on a square foot basis) of view versus non-view lots are 27% ($1.26/sft). This assumes assumption that frontage view lots will sell at the same price as regular view lots when in reality, it is likely that the frontage view lots will sell for much higher amounts (possibly 26% more based on asking price differentials between view and frontage lots). Therefore a lower bound estimate for the view premium for all view lots in the subdivision (including nine substitute residential lots) is $1.7 million (Table 2.7).

Access premiums based on comparisons of the sale price of the smaller sized non-view lots at Elk Ridge (i.e. Villas) with similar sized and non-view lots at three other nearby subdivisions (shown in Figure 2.10), are as follows: Non-view access premiums are 58% or ($1.72/sft.) which totals $2.2 million. Alternatively, access premiums for view lots were calculated by subtracting view premiums of $1.26/sft from the average value of all view lots ($5.26/sft.) and then multiplying this value by the estimated access premium of 58%. The resulting access value for view lots therefore separates view and access values and is $2.73/sft. which is 46% of the value of view lots and generates access values for view lots of $3.6 million. Combined view and access premiums are $7.7 million.

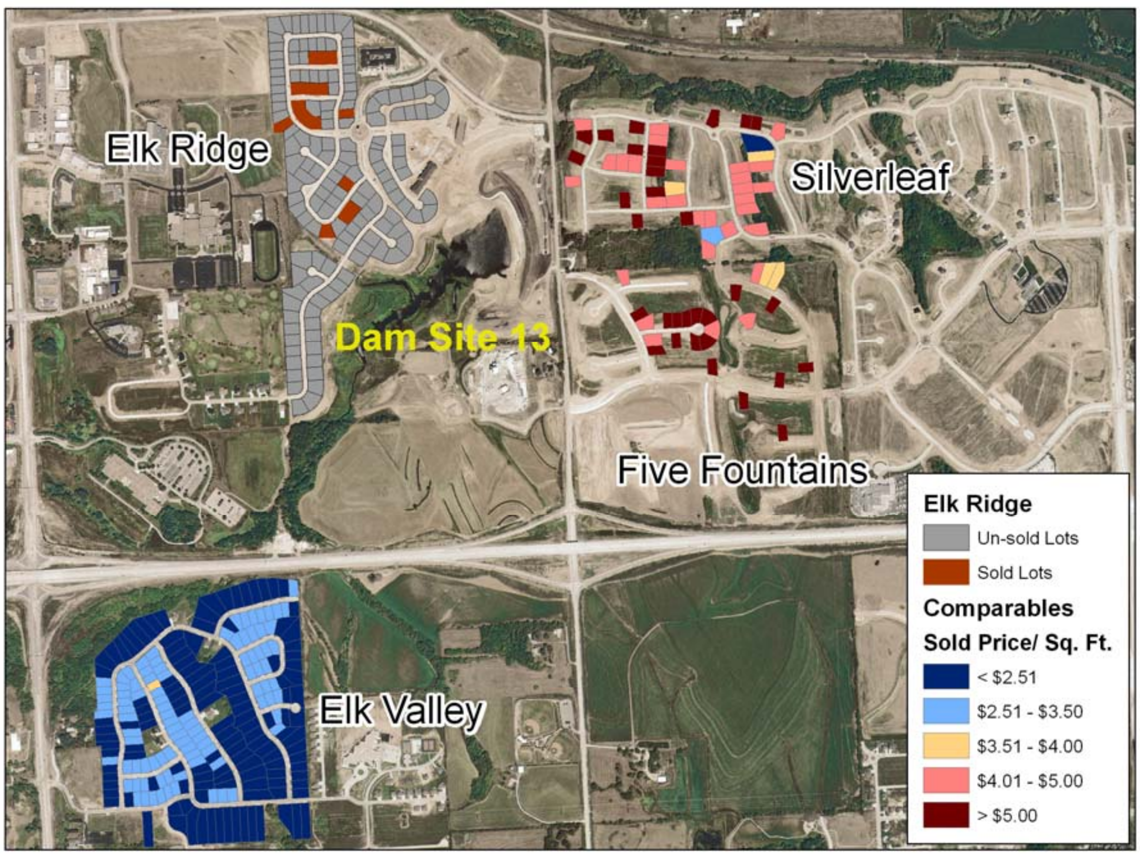


Figure 2.10. Sold Comparisons Across Four Subdivisions

Both the view and access premiums captured by the Elk Ridge Developers as a result of the creation of Dam Site 13 are considerably higher than those observed at other area lakes. This is assumed to be a direct result of level of exclusivity and privacy (i.e. lack of public access) associated with the Elk Ridge development. While technically it is true that Elk Ridge lot owners do not have exclusive (100%) private access to the lake, they for the most part, they have captured accessibility and frontage characteristics of the lake since no public parking or access points are located on the western or northern shores of the lake, meaning that lake access for the majority of the public will have to be through the southern shore (Memorial Park) area. As well, the frontage lots at Elk Ridge come very close to the shoreline which enhances the value of frontage lots but could potential threaten the long-term water quality of the lake due to potential fertilizer run-off from adjacent lawns.

There are three possible scenarios that could lead to Elk Ridge lake view and access premiums being lower than the values estimated by this study. First, if the already built senior care/living building and the planned condo/office developments are actually less valuable than residential lots, then actual premiums will be lower than estimated. Second, it may be that the Elk Ridge development is of higher quality than the other nearby subdivisions for which lot price comparisons were made in order to determine access values. In particular, we have noted that the promotional website for the Elk Ridge development is of higher quality, and the multi-housing style aspects of the development as well as the road planning and lot preparation of this development appear to be superior to those observed in the other subdivisions. While these impacts may exist they are difficult to quantify and it is unlikely that they themselves would explain the large price premiums discovered at Elk Ridge. Third, it is possible that access values to the lake may be influenced by the close proximity to the nearby high school, the golf course and/or the city park that is adjacent to the lake (Memorial Park West). The park amenity value is particularly interesting since it may be creating a prestige factor since in the last century many of the most valuable homes in Omaha were built around Memorial Park East. Therefore, we are proposing some follow-up studies that would further evaluate these issues (these are described in the next section).

In summary, the developer of the Elk Ridge subdivision made a $1.6 million contribution to the project (a $1,000,000 cash contribution in year 1, interest payments of 7.5% interest on $180,000, and final balance of balance of $480,000 to be paid in 2010. Comparing these discounted project costs to the present value of expected lot sale premiums (spread out from years 2 through 5 of the project which results in a value of $6 million) generates an estimated rate of return of 437% or an annual return of 87% per year over 5-years (table 2.7).

Table 2.7. A Summary of Captured Premiums and Returns at Dam Site 13

	View Premiums	Access Premiums		Total Premiums
		Non-View Lots	View Lots [b]	
Level of Analysis	*Within Elk Ridge*	*Elk Ridge Vs. 3 Subdivisions*	*Based on non-view Access Premium* [d]	
Comments				
Sample Size (sold comparisons)	18	370	225	613
Premium %	27% [a]	58% [b]	46% [c]	
Premium $	$1.26	$1.72	$2.73	
Total Square Feet	1,378,609 [b]	1,291,119	1,378,609[b]	
Total Premium Value	$1,737,047	$2,220,725	$3,625,742	**$7,715,860**
Present Value of Premiums (5 years, 7.5%)				**$6,009,984**
Discounted Marginal Return				**437%**
Discounted Annual Return				**87%** [d]

<u>Explanatory Notes:</u>

a. This is a lower-bound estimate as frontage/view lots are combined with non-frontage view lots (they are assumed to have the same value because no frontage/view lots have yet sold). Since frontage/view asking prices are 36% higher than non-frontage view lots, actual view premiums are likely higher

b . Includes five view/frontage lots where the Assisted Living Building is on the northwest shore of the lake and 4 view/frontage lots where the condos are located on the western shore (based on average view lot sizes of 17,821 sqft)

c. Estimated by multiplying the difference between average view lot values ($5.96) and view premiums ($1.26) by the estimated access premium of non-view lots (58%).

d. If a 10% discount rate is used the discounted average annual return is 84%.

Summary and Policy Implications

This analysis of the relationships between residential housing and lot sales surrounding five different Omaha area man-made lakes indicates that reasonably large but varied price premiums are associated with view and access amenities associated with the lakes. It appears that landowners and/or developers capture the majority of those premiums at the time the lakes are constructed. It is also evident and that the level of exclusivity or privacy of the lake and residential housing designs has a large impact on the magnitude of the premiums that are captured by developers (i.e. captured amenity values increase with exclusivity and decline with public facilities, land buffers and/or access).

This Dam Site 13 analysis is of particular interest since it is the first ‘public-private lake construction partnership’. In this case, the developer appears to have been very well compensated for their participation. However, before a final conclusion is drawn regarding the extent to which the PMNRD potentially under-charged their private partner, additional analyses and follow-up studies are warranted. In particular, continued analyses of lot sales are planned and it is proposed that a hedonic valuation model of lot sales be conducted at Elk Ridge and nearby subdivisions in order to determine whether or not some of the access value premiums at Elk Ridge have been influenced by other (non lake related) factors. Nevertheless, based on these preliminary study results, if and when the PMNRD or others plan additional public-private partnerships for the purposes of lake construction, it is recommended that:

1) Higher contributions be sought from private developers (increased cash payments or reduced land sale prices). This could be facilitated by relying on empirical research (such as this report) which quantifies view and access premiums that can be expected from different types of lake designs.

2) Scenarios be considered where the PMNRD purchase entire land parcels (quarter to full sections of land), and then after planning and/or constructing a lake, conduct a public auction off available adjacent residential development areas (either all together or in individual sections). This would help ensure that a fair

(‘market’) price is paid for land adjacent to publicly funded lakes. Again, empirical research which quantifies ranges of possible view and access premiums could help developers determine optimal bid prices for land adjacent to lakes.

3) In cases where it is not possible to negotiate a mutually acceptable fair market price for land adjacent to man-made lakes, the PMNRD should consider having larger public buffer areas surrounding lakes which would ensure more public access, improved recreational opportunities, and better water quality in the lakes. At a minimum, such policies would ensure that the public captures all (or at least most) of the economic amenity values that are created with public funds.

Suggested Future Research

1) Conduct a hedonic price analysis of sold lots at Standing Bear, Zorinsky, and Dam Site 13 that account for lot-specific characteristics (size, shape, location, nearby land uses, etc) in order to better quantify the access values of lakes.

2) Continue to collect and monitor both lot and housing sales at Dam Site 13 and in the nearby subdivisions to confirm view and access premium estimates over time and to conduct a more detailed hedonic price analysis of these access based amenity values.

3) Conduct surveys of homebuyers at Dam Site 13 and nearby subdivisions to identify factors that may have influenced their purchase decisions and in particular to assess the importance of lake views, access, and other factors.

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LID, Open Space and Single Family Housing Values

Background and Study Objectives

In the Omaha Metropolitan Area, typical Midwestern urbanization trends are the cause of increasing flooding and water quality problems. One proposed solution is the promotion (or requirement) of Low Impact Developments (LIDs) which can generally be defined as the use of Best Management Practices (BMPS) ranging from more impervious surface materials to local retention basins, and other measure that jointly reduce surface runoff from precipitation events. Alternatively LIDs in the context of subdivision designs, provide for a ‘de-centralized’ management of stormwater. That is, LIDs attempt to mimic naturally hydrology by using techniques that capture storm water where it falls.

One of the critical questions regarding the feasibility (in addition to their cost and their effectiveness in reducing runoff) is how LIDs will be perceived and accepted by homebuyers and, in particular, if they will pay a premium or discount for homes within LID subdivisions. Therefore, the focus and goal of this present research is to determine homebuyer preferences for different types of subdivision open space design that is intended to proxy for alternative LID designs. For example, do homebuyers prefer clustered or more open landscape design? Do they prefer managed or native/natural plant systems? What are their preferences for trails, public recreation access, and trees? And finally, do they prefer these open spaces to be publicly or privately managed?

The classic example of an LID subdivision involves *clusters* of homes, often with small lots, surrounded by publicly-owned open-space (Figure 3.1). The open-space is usually planted in natural vegetation and may or may not have trails and other recreational features. Another example of LID is the use of *greenways* where **not** all homes abut (face) the open space, yet all residents have access to a relatively large undeveloped open space area (Figure 3.1). Open space areas can be publicly or privately owned or managed (by city or county governments, Natural Resource Districts, utilities, homeowner associations, or even SIDs).

Figure 3.1 An Example of Clustered Low Impact Development

Figure 3.2 An Example of Greenway Low Impact Development

No actual LID subdivisions (designed exclusively for storm water management and with a history of housing sales) currently exist in the Omaha area. However, a wide variety of different subdivision designs with respect to quantities and types of open space do exist. It is hypothesized that homebuyers will be most concerned with the open space components of different LID designs when they are deciding whether or not to purchase a home and/or how much to pay for that home. In other words, open space designs are assumed to proxy for different LID designs. It is important to note however that open space requirements for new subdivisions are currently regulated by non-LID goals in Douglas County.

These research results are expected to be useful to both the public and private sector. In particular it is expected that real estate developers and builders will have a greater self-interest in developing LID subdivisions if they can be shown the relative profit levels they can obtain from different open space/LID subdivision designs. From the public sector perspective, it is also necessary for planners and/or regulators to understand the homebuyers' preferences for open space designs, and hence potential profit margins for developers who build LID subdivisions. For example, if it turns out that a particular open space design leads to property price premiums then the value of these premiums could potentially offset some (if not all) of the potential LID development costs borne by developers. Alternatively, if it was discovered that a particular LID/open space design was discounted by homebuyers, the public (through local governments) might justify subsidizing developers who voluntarily adopt such LID designs.

Methods and Procedures

The study area is based in Douglas County and encompasses all of the area North of Harrison Street, South of Lake Cunningham Road, East of 204th Street, and West of I680/I80. The study area was chosen because it contained a large percentage of undeveloped land and the drive time to major employment centers (downtown Omaha) was similar for the entire area (Figure 3.3). Furthermore, most homes in the area are of newer construction (post-1950) therefore eliminating much of the modeling difficulties associated with older historical neighborhoods. In addition, newer development often exhibits high degrees of housing homogeneity (many similar home styles and sizes). For example, see the price consistency (and clustering) of homes across 321 different subdivisions across the study area (Figure 3.3).

The real estate transaction database used for this study was the same one used for the floodplain impact study described earlier except it focused on different areas and included sales up to May 30, 2007. Again this database includes sales transaction and housing characteristics data from the Multiple Listing Service with county parcel and housing data, all within a GIS framework. Only sales that are contained in a platted subdivision are used in the analysis. Other homes that may have sold in the study area but were either original farmsteads or were platted independently on an individual basis were removed from the sample. The resulting sales are shown in Figure 3.3.

This research effort required the estimation of 14 different hedonic price models. Alternative models were needed to evaluate different types of open space amenities at different levels of spatial scale (for example, subdivisions versus buffers of different sizes). The focus was to evaluate open space impacts on housing prices from the perspectives of public versus private ownership and management of the open space, the type of open space measured by it's groundcover type, and location aspects (distances abutments, etc). A reporting of all the model results is beyond the scope of this present study report but readers interested in the full study results should refer to the Masters Thesis of Nick Schmitz after April 1, 2008.

All of the estimated hedonic price models share a set of explanatory variables intended to account for structural housing, lot and neighborhood factors. These variables are listed in Table 3.1

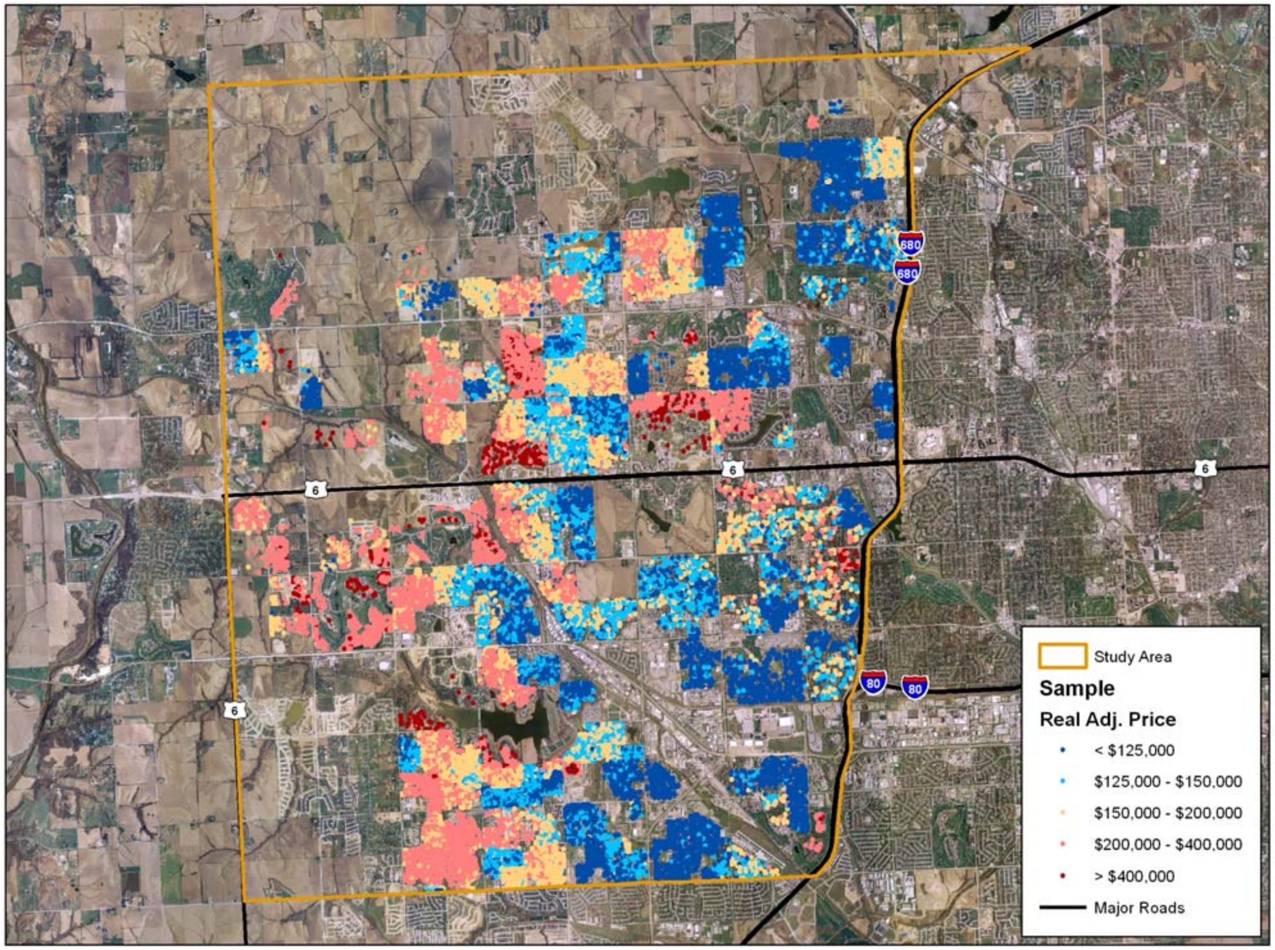

Figure 3.3 Study Area with Sales and Prices shown as Classes of Points

Table 3.1 Explanatory Variable Descriptions and Expected Signs

Variable	Description	Source	Expected Sign
LN Lot Size	Size of Lot in Square Feet	County	+
LN House Size	Finished Square Feet of the House	MLS[a]	+
Age	Age in Years	MLS	-
D New	Dummy = 1 if House is New	MLS	+
D Walk Out	Dummy =1 if Walk Out Basement	MLS	+
Fireplaces	Number of Fireplaces	MLS	+
Garage Stalls	Number of Garage Stalls	MLS	+
D 1.5 Story	Dummy = 1 if 1.5 Story House	County	+
D 2 Story	Dummy = 1 If 2 Story House	County	+
D Split Foyer	Dummy = 1 if Split Foyer	County	-
D Ranch	Dummy = 1 if Ranch	County	+
D 1997	Dummy = 1 If Sold Year is 1997	MLS	+
D 1998	Dummy = 1 If Sold Year is 1998	MLS	+
D 1999	Dummy = 1 If Sold Year is 1999	MLS	+
D 2000	Dummy = 1 If Sold Year is 2000	MLS	+
D 2001	Dummy = 1 If Sold Year is 2001	MLS	+
D 2002	Dummy = 1 If Sold Year is 2002	MLS	+
D 2003	Dummy = 1 If Sold Year is 2003	MLS	+
D 2004	Dummy = 1 If Sold Year is 2004	MLS	+
D 2005	Dummy = 1 If Sold Year is 2005	MLS	+
D 2006	Dummy = 1 If Sold Year is 2006	MLS	+
D 2007	Dummy = 1 If Sold Year is 2007	MLS	+
D Double Frontage	Dummy = 1 if Lot is Double Frontage Lot i.e. Abuts Two Streets	Aerial Photos[b]	-
D Floodplain	Dummy = 1 if Home is in the Floodplain	FEMA [cf]	-
Housing Density	Housing Units per Square Mile	US Census[f]	-
LN Dist. Com	Distance to Commercial Property in Feet	County[f]	+
LN Dist. Ind	Distance to Industrial Property in Feet	County[f]	+
LN Dist. Arterial Road	Distance to Arterial Road in Feet.	MAPA[df]	?
LN Dist. Dodge St.	Distance to Dodge Street in Feet	ESRI[ef]	?
LN Dist. I80/I680	Distance to I80/I680 in Feet	ESRI[ef]	?
LN Dist. High School	Distance to Nearest High School in Feet	Douglas County[f]	?
LN Dist Other School	Distance to Nearest Middle/Elementary School in Feet	Douglas County[f]	?
D Omaha	Dummy = 1 if Omaha Public School District	MLS	-
D Millard[g]	Dummy = 1 if in Millard Public School District	MLS	-

[a] Great Plains Multiple Listing Service (MLS)
[b] Manual Classifications
[c] Federal Emergency Management Agency (FEMA) Digital Flood Insurance Rate Map (DFIRM)
[d] Metro Area Planning Association (MAPA)
[e] Environmental Systems Research Institute
[f] Spatially Integrated With Sale Points using GIS
[g] Omitted Classification is Elkhorn School district which is generally considered to be the preferred district in the study area

Classifying Open Space Conditions

A wide variety of open space models intended to proxy for alternative LID subdivision designs were evaluated. These are summarized in Table 3.2 and shown in a map in Figure 3.4. Recall however, that not all these variables are contained in a single hedonic model. Images showing examples of these open space variables at different levels of geographic scales (for example, within subdivisions, buffers, and for abutting properties) are shown in Figures 3.5 to 3.10.

The procedures used to quantify these open space characteristics involved complex GIS operations which are described in detail in Schmitz (2008) and summarized here. Each open space parcel is grouped into one of five ownership classes: homeowners association, sanitary improvement district (SID), public, private, and golf course. Homeowner association parcels are owned jointly by all residents of the subdivisions who pay dues to the homeowners association who in turn manages the open space along with other aspects of the neighborhood. SID-owned parcels are in new subdivisions which have not been formally annexed into the city. Public parcels can be owned by local governments such as the City of Omaha or the PMNRD, or other public entities. In most instances these parcels are managed as public parks with varying levels of accessibility. Private parcels are owned by individuals, in many instances they are tilled and placed in row crops or pasture.

Besides ownership type, explicitly defined characteristics for each parcel were made using manual classifications. These open space classifications were made qualitatively based on GIS land use coverages, street and subdivision designs, and NAIP aerial imagery. Specifically the presence of trails, parking lots, pool, baseball diamonds, or soccer fields was noted for each parcel. Groundcover variables are defined as percent trees, mowed, prairie, wooded and tilled. It should be recognized that ground cover is inherently complex and can be represented by different plant species grouped into different distributions. Percentage values of these land uses are calculated in an effort to simplify the description of each parcel.

The study characterizes *mowed* areas as any manicured grass not covered or shaded by a tree canopy with *trees* being shade trees in a maintained setting, i.e. the grass underneath them is mowed such as one would find in a city park. *Grass* (not mowed) and *prairie* are grouped into a single category, while there are a number of prairie restoration projects in the study area it is impossible to distinguish these from parcels simply planted in grass. Wooded areas are considered different from trees in that the ground underneath the canopy is not maintained in any way. Finally, tilled parcels were almost all located on the fringe of the city and in almost all instances only affect the new homes in the sample.

After defining the characteristics for each parcel the objective is to summarize these proximate open areas with respect to the sold homes in the sale sample. The literature and conventional wisdom describe three distinct ways to reference a parcel with respect to open space, abutments where a lot borders an open area, neighborhoods where a home references a defined area around itself, and proximity which in this study is the Euclidean (straight line) distance in feet to an open area. Finally, a home is defined as abutting open space when its lot boundary is shared with an open area. Lots located directly across the street from common areas are not considered as abutting open space. For abutment parcels each groundcover type is measured as a percentage within neighborhoods for each parcel and expected signs being positive except for woods which may be negatively signed due to perceived externalities such as animal populations or lack of maintenance.

Neighborhood classifications (in which a parcel was located) were made using two defined areas through which the percentage of open space can be estimated and taken into consideration by home buyers. Neighborhoods can be defined as 400 meter buffers and platted subdivisions. This study does not attempt to determine the long-term existence of open space that currently exists.

Ownership type is measured both on a neighborhood percentage basis and by distance calculations (distance to the nearest of each type). The effects of ownership type are unknown. No known studies have shown a significant *negative* relationship between ownership types of open space and home values although some discussion of negative externalities has been noted (Dehring and Dunse 2006) and other researchers have noted that ownership types will realize different magnitudes in effects (Irwin 2002).

Due to the conjunctive use of groundcover and ownership variables in this study it is expected that certain open space amenities may appear to negatively impact property values not because of the open space amenity per se, but rather because of who owns or manages the open space. For that reason the study makes the distinction between public and privately-owned open space throughout the analyses.

The hedonic models are also estimated separately for homes that are near open space and homes that actually abut open space. This is considered particularly important when analyzing public facilities such as trails, parking lots, pools, baseball diamonds, and soccer fields. Pools and trails are expected to positively impact housing prices as they are a positive use amenity. Parking will likely have negative effects on parcels since parking lots allow people outside the neighborhood or immediate area to use the park. Both baseball and soccer fields will likely have negative signs due to the noise and congestion associated with sporting events.

Table 3.2 Open Space Variables and Expected Signs

	Variable	Description	Expected Sign
Percentages	*Within Neighborhoods*		
	% Trees	% Trees within the parcel (i.e. trees where grass underneath is mowed; shade trees)	+
	% Mowed	% of the parcel that is mowed and not covered by trees i.e. open mowed fields	+
	% Grass/Prairie	% of the parcel that is planted in un-mowed grass or natural prairie	+
	% Wooded	% of the parcel that is wooded i.e. non manicured trees or forests	-
	% Tilled/ Farmed	% tilled or farmed this can be row crops or hay land	+
Distance to and Percentages	*In Proximity and Within Neighborhoods*		
	Homeowners Association	If parcel is owned by a homeowners association	?
	SID	If parcel is owned by an SID	?
	Public	If a parcel is owned by a public entity i.e. County, City, etc.	?
	Private	If the parcel is owned by a private individual or company	?
	Golf Course	If the parcels land use is a gold course or is owned by a particular golf course	?
Dummies	*Individual Open Space Parcels*[a]		
	Trails	If there are visible trails on the parcel	+
	Parking	If there is a parking lot on the parcel	-
	Pool	If there is a pool on the parcel	+
	Tennis	If there are tennis courts on the parcel	+
	Baseball	If there is baseball/softball diamond on the parcel	-
	Soccer	If there is a soccer field on the parcel	-

[a]Analyzed only with respect to abutment homes in this report (mainly due to the fact that within neighborhoods it would be impossible to tell the relative location of these amenities/disamenities to other parcels)

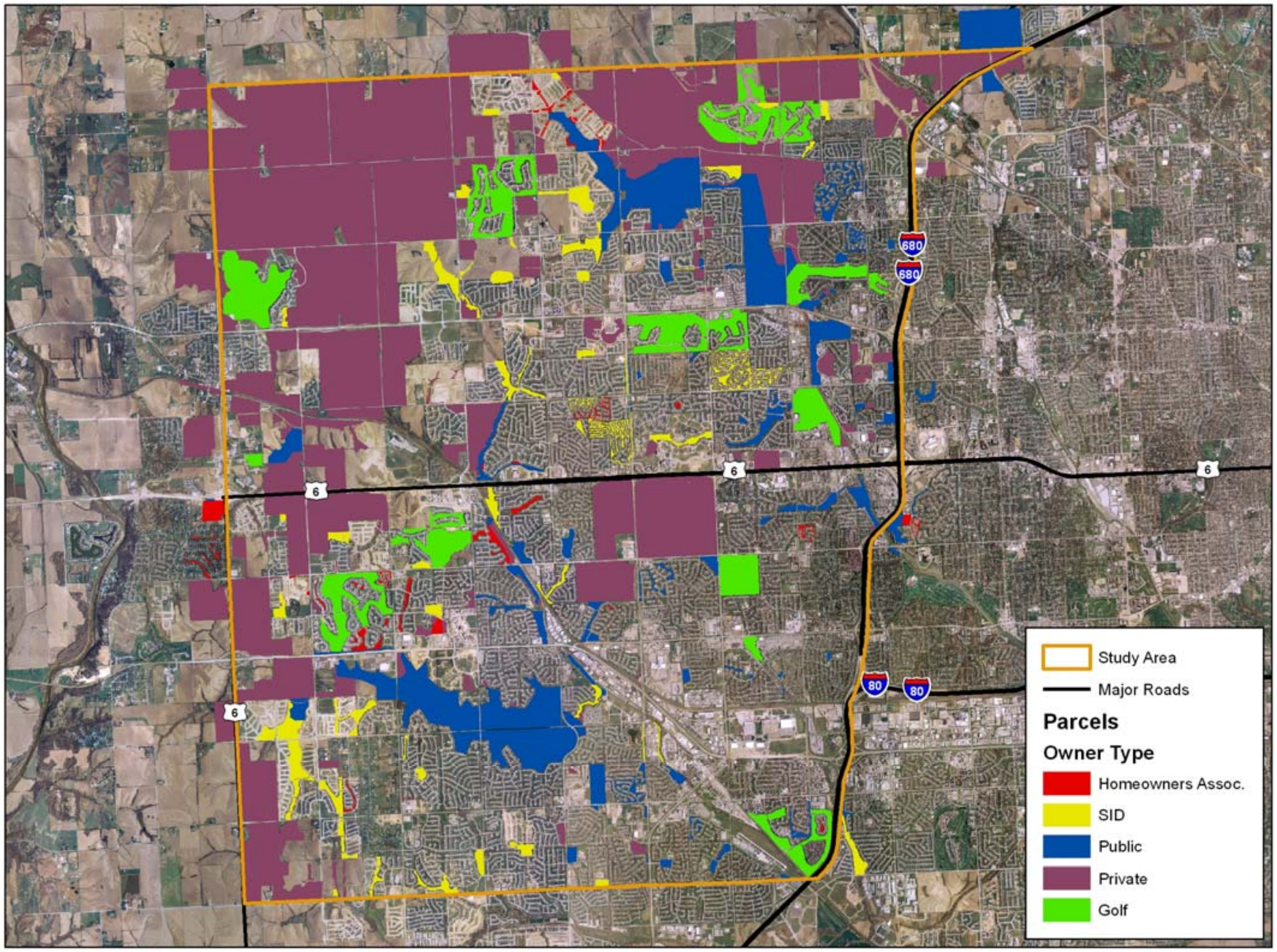

Figure 3.4 Distribution of Open Space in the Study Area

Figure 3.5 Open Space With Baseball Diamonds, Trails, and Parking

Figure 3.6 Open Space with 50% Trees and 50% Mowed

Figure 3.7 Open Space 80% Grass/Prairie and 20% Wooded

Figure 3.8 100% Tilled Open Space

Figure 3.9 Parcels Abutting Open Space (Shown in Red)

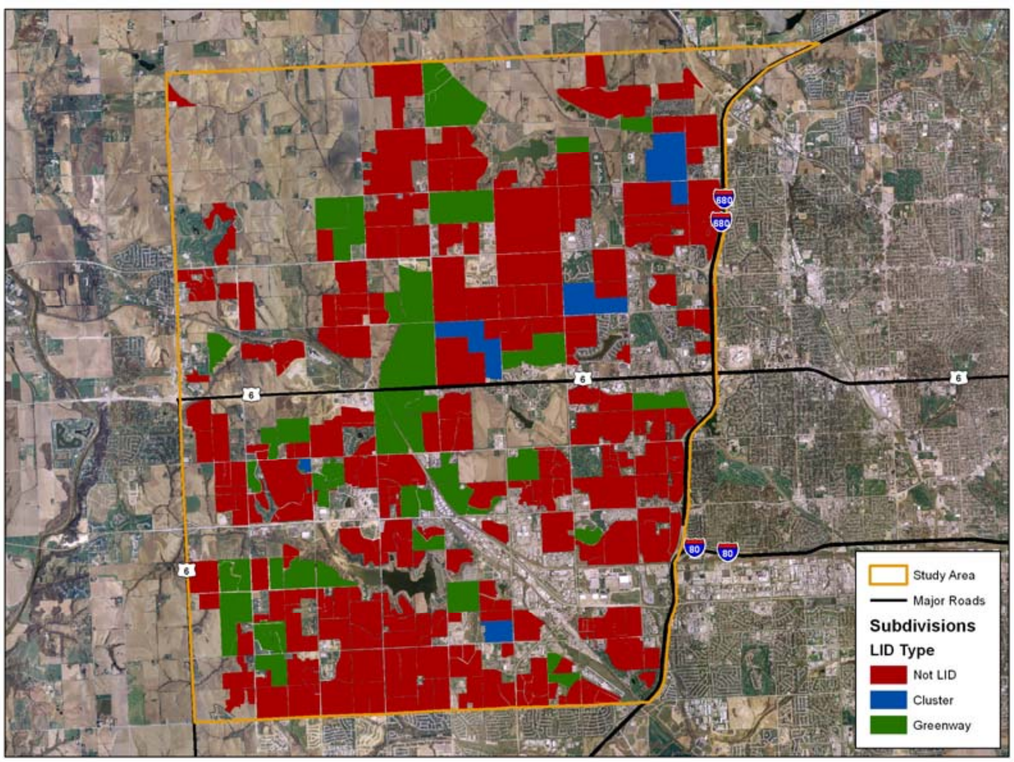

Figure 3.10 Emphasis Subdivisions by LID Type

Results

Table 3.3 summarizes the mean sale prices of homes by open space percentages across subdivisions across the study area. In general, as open space increases within a neighborhood, home values tend to increase and the highest open space premiums appear to be in neighborhoods with at least 20% open space

Table 3.3 Prices by Open Space Percentages Across Subdivisions

Percent of Open Space	Mean	Median	Min	Max	n
<5%	$161,583	$145,391	$64,294	$981,395	10,117
5% - 10%	$183,419	$181,750	$63,103	$624,205	3,706
10% - 20%	$190,317	$135,927	$67,673	$789,123	2,543
20% - 40%	$176,687	$156,451	$71,324	$539,522	1,781
> 40%	$248,621	$247,087	$80,479	$629,203	245

Table 3.4 adds an additional dimension to the analysis of housing prices and open space by including the size of sold parcels. This required omitting parcels that directly abutted open spaces since these parcels tended to skew the results. It can be seen that prices tend to increase as open space increases with smaller lot sizes. With larger lot sizes these results are not consistent. In particular, prices in bold in the table indicated incidences where prices tend to have fallen with more open space. The two conclusions from this are: 1) Public open space is likely less important to large parcels that often have their own open space, and in fact this open space is publicly managed may have a negative impact on its relative value; 2) More complex (multivariate) analyses of the factors influencing sale prices are needed .

Table 3.4 Mean Housing Prices by Open Space and Lot Classes (in subdivisions)

	Acres			
% Total Open Space	<0.2 Acres	0.2 – 0.25	0.25 – 0.3	>0.3
<5%	$129,449	$162,172	$180,423	$218,936
5% - 10%	$126,239	$188,885	$217,909	$243,988
10% - 20%	$125,953	$155,367	$215,897	$345,687
20% - 40%	$130,035	$183,065	$198,523	$239,224
> 40%	$111,754	$166,834	$292,887	$373,117

Finally, Table 3.5 shows how sale prices change mean prices by distance away from different types of open space that are categorized across ownership types. From this it can be seen that in general home values are positively related to private open space versus a negative impact associated with publicly-owned open space.

Table 3.5 Housing Prices by Distance Classes across Ownership Type

Distance Classes (ft)	Homeowner Assoc.	SID	Public	Private	Golf
<500	$253,281	$187,172	$153,523	$187,973	$231,490
500-1000	$221,835	$214,835	$156,425	$175,766	$184,720
1000 – 2000	$190,566	$232,192	$162,605	$174,344	$160,633
2000 – 4000	$172,619	$179,011	$188,488	$176,079	$162,096
>4000	$156,033	$144739	$211,389	$131,086	$174,224

Hedonic Price Estimates

The hedonic price regression results for the model that measures the impact of open space within different ownership classes is presented in Table 3.6. In this case the relationship between sold homes and open space ownership classes is measured by distances between them (i.e. proximity). Most variables are statistically significant with their expected signs (i.e. their impacts on sale prices are as expected). The adjusted coefficient of determination is 0.88 indicating that the model explains 88% of the variation in home prices. The f-statistic of 3429.92 signifies that all variables considered jointly have a statistically significant impact on price at the 1% level.

In this model, the distance to open space coefficient is negative and significant indicating that as homes are closer to open space they increase in value. Ownership classification are statistically insignificant in this model and this is expected to be a result of the distance measure not accounting for abutments and/or the actual open space amenities associated with particular neighborhoods or subdivisions. Ownership issues are further evaluated in subsequent models.

Table 3.6. Hedonic Results Related to Open Space Ownership Impacts

Variables	Ownership Dummies				Ownership Distances		
	Coef.	*Sd. Err.*	*p>|t|*		*Coef.*	*Sd. Err.*	*p>|t|*
LN Lot Size	0.197	0.004	0.000		0.195	0.004	0.000
LN House Size	0.534	0.005	0.000		0.525	0.005	0.000
Age	-7.6E-03	1.5E-04	0.000		-8.2E-03	1.6E-04	0.000
D New House	0.074	0.004	0.000		0.075	0.004	0.000
D Walk Out	0.026	0.002	0.000		0.029	0.002	0.000
Fireplaces	0.039	0.002	0.000		0.039	0.002	0.000
Garage Stalls	0.081	0.002	0.000		0.081	0.002	0.000
D 1.5 Story	0.139	0.007	0.000		0.136	0.007	0.000
D 2 Story	0.037	0.003	0.000		0.032	0.003	0.000
D Split Foyer	-3.2E-02	0.003	0.000		-3.0E-02	0.003	0.000
D Ranch	0.060	0.003	0.000		0.053	0.003	0.000
D 1997	-3.6E-02	0.005	0.000		-3.7E-02	0.005	0.000
D 1998	-7.1E-03	0.005	0.146		-7.6E-03	0.005	0.118
D 1999	0.029	0.005	0.000		0.029	0.005	0.000
D 2000	0.037	0.005	0.000		0.038	0.005	0.000
D 2001	0.037	0.005	0.000		0.039	0.005	0.000
D 2002	0.053	0.005	0.000		0.055	0.005	0.000
D 2003	0.065	0.004	0.000		0.067	0.004	0.000
D 2004	0.079	0.004	0.000		0.083	0.004	0.000
D 2005	0.074	0.004	0.000		0.079	0.004	0.000
D 2006	0.057	0.004	0.000		0.062	0.004	0.000
D 2007	0.043	0.005	0.000		0.049	0.005	0.000
D Double Front.	-5.0E-02	0.004	0.000		-5.0E-02	0.004	0.000
D Floodplain	-4.4E-02	0.011	0.000		-2.6E-02	0.011	0.018
Housing Density	-2.5E-05	1.8E-06	0.000		-2.8E-05	1.8E-06	0.000
LN Dist. Com.	-1.7E-03	0.001	0.220		9.1E-04	0.001	0.505
LN Dist. Industrial	0.021	0.002	0.000		0.016	0.002	0.000
LN Dist. Art. Road	-1.6E-03	0.001	0.232		0.001	0.001	0.355
LN Dist. Dodge St.	-1.9E-02	0.002	0.000		-1.1E-02	0.002	0.000
LN Dist. I80/I680	-1.7E-02	0.002	0.000		-1.5E-02	0.002	0.000
LN Dist. H. Sch.	-6.3E-03	0.002	0.000		-8.1E-03	0.002	0.000
LN Dist O. Sch.	0.006	0.001	0.000		0.007	0.001	0.000
D Omaha	-4.1E-02	0.004	0.000		-9.1E-03	0.005	0.048
D Millard	-1.9E-02	0.004	0.000		0.003	0.005	0.529
LN Dist Open	-1.3E-02	0.001	0.000		-	-	-
D Homeowners’	8.8E-04	0.006	0.873	**LN Dist**	-2.5E-02	0.001	0.000
D SID	-4.3E-02	0.005	0.000	**LN Dist**	0.007	0.001	0.000
D Public	-3.9E-02	0.004	0.000	**LN Dist**	0.001	0.001	0.232
D Private	-5.4E-02	0.004	0.000	**LN Dist**	0.004	0.001	0.001
D Golf[a]	-	-	-	**LN Dist**	-1.6E-02	0.002	0.000
Constant	6.248	0.057	0.000		6.372	0.059	0.000
Observations		18392				18392	
F-Value		3429.92				3565.81	
Prob > F		0.000				0.000	
R-squared		0.8820				0.8834	
Adj. R-squared		0.8818				0.8832	
Root MSE		0.13145				0.13067	

Note: Ownership Delineated by Dummy Indicators and Through Separate Distance Variables

[a] Dropped to prevent a dummy variable trap, represented by the constant or intercept.

Ownership and Groundcover Impacts by Area Analyses

The full hedonic regression results that evaluate open space from an ownership perspective and by different groundcover classifications are summarized in Table 3.7. The thesis document of Schmitz (2008) contains the reporting of these full regression model results.

Table 3.7. Price Impacts: Ownership & Groundcover

	% Homeowners	% SID	% Public	% Private	% Golf
% Trees	30%	14%	14%	24%	27%
% Mowed	15%	-1%	-1%	9%	12%
% Prairie/Grass[a]	7%	-8%	-9%	1%	4%
% Wooded	18%	2%	2%	12%	15%
% Tilled/Farmed	-14%	-30%	-30%	-20%	-17%

Note: For a $172,356 Home With 30% Open Space.
[a] Coefficient was not significant at the 10% level in the subdivision model.

Table 3.7 demonstrates the relative impacts that both ownership status and open space groundcover have on residential housing prices. For example, homes with nearby tree dominated open space which is homeowner association owned has 24% of their value impacted by this open space scenario. Alternatively, 24% of the value of such homes is influenced by this nearby privately owned tree open space. From this it can be that all types of open space increase property values (except for the case of farmland next to subdivisions). SID-managed open space in most cases has a negative impact on property values (unless it is in trees or woodlands). Finally, golf course-based open space is positive under all ownership classes while native prairie or mowed open space is positive only when these spaces are privately owned and managed.

Open Space Impacts for Abutment Homes

Table 3.8 summarizes the hedonic regression models that specifically focused on sold homes that abutted open spaces (i.e. frontage homes). From this it can be seen that the presence of trails increases values by around 17.2%, i.e. if a home abuts a parcel with trails its value will increase considerably. Parking lots, as expected, cause a negative stigma. The presence of a pool is insignificant possibly because this can be both a positive or negative amenity depending on tastes and preferences. Baseball and soccer fields are both negatively signed indicating that homeowners prefer not to abut parcels with these amenities which is expected due to the noise and congestion associated with baseball, soccer, and football games.

Table 3.8 Impacts of Recreation Amenities on Housing Prices

Variable	Percentage Effect
D Trails	17.20%
D Parking Lot	-16.52%
D Pool	3.80% (insig.)
D Tennis	29.80%
D Baseball	-12.26%
D Soccer	-9.25%

Hedonic Results Specific to LID Subdivision Designs

Table 3.9 evaluates the impact of two particular types of LID subdivision design on property values: clustered open space versus greenway open space. The greenway subdivisions generate a premium of between 1.1% to 2.74% depending on whether greenway areas were observed or calculated using a GIS approach. In contrast, the impacts of clustered subdivisions range from 0.7% to 1.1%. These are considered to be lower-bound estimates since homebuyers will likely be willing to pay for non-open space related benefits of LID designs (i.e. ‘green’ or ‘environmentally friendly’ developments).

Table 3.9. A Summary of LID/Subdivision Price Impacts

Variable	Greenway Observed			Greenway Calculated[a]		
	Coef.	*Sd. Err.*	*p>|t|*	*Coef.*	*Sd. Err.*	*p>|t|*
D Double Front.	-4.6E-02	0.004	0.000	-4.5E-02	0.004	0.000
D Floodplain	-4.4E-03	0.010	0.673	-6.1E-03	0.010	0.558
Housing Density	-2.8E-05	1.8E-06	0.000	-2.6E-05	1.8E-06	0.000
LN Dist. Com.	-2.8E-03	0.001	0.034	-2.3E-03	0.001	0.091
LN Dist. Industrial	0.019	0.002	0.000	0.020	0.002	0.000
LN Dist. Art. Road	-1.6E-03	0.001	0.222	-5.6E-04	0.001	0.671
LN Dist. Dodge St.	-1.9E-02	0.002	0.000	-2.0E-02	0.001	0.000
LN Dist. I80/I680	-1.3E-02	0.002	0.000	-1.5E-02	0.002	0.000
LN Dist. H. Sch.	-4.1E-03	0.002	0.007	-5.4E-03	0.002	0.000
LN Dist O. Sch.	0.006	0.001	0.000	0.004	0.001	0.000
D Omaha	-4.2E-02	0.004	0.000	-4.6E-02	0.004	0.000
D Millard	-2.4E-02	0.004	0.000	-2.6E-02	0.004	0.000
D Cluster	0.007	0.006	0.225	0.011	0.006	0.065
D Greenway	0.014	0.003	0.000	0.027	0.002	0.000
D Abut Open	-8.6E-03	0.006	0.134	-8.5E-03	0.006	0.138
Constant	6.062	0.055	0.000	6.092	0.055	0.000
Observations		19,589			19,589	
F-Value		3917.51			3940.94	
Prob > F		0.0000			0.0000	
R-squared		0.8811			0.8818	
Adj. R-squared		0.8809			0.8815	
Root MSE		0.1327			0.1323	

[a] Subdivision is Considered Greenway if it has > 10% Open Space

Summary and Policy Implications

This research has direct implications for policy makers and developers planning residential housing developments in the Omaha market that include open space amenities and/or LID practices (also known as 'conservation design'). Clustered open space tends to negatively impact sale prices or in some cases have neutral effect. In contrast, the more wide open greenway-based open spaces have larger positive impacts on home prices. It is also clear that home buyers prefer open space to be owned and maintained by a homeowners association or a private entity and that they prefer open areas to be mowed and/or planted in trees. In conclusion, while many types of open space generate positive values there are some combinations of open space, ownership and ground cover characteristics that negatively impact property values.

Planners and residential housing developers are suggested to evaluate the specific neighborhood and open space conditions associated with existing and planned subdivisions in conjunction with these research results (particularly the full thesis results of Schmitz, 2008). Combined with information on the relative costs to plan, design and build specific open space amenities, this information is expected to maximize homeowner preferences and hence development profits. In the case of planning LID/open space designs, it is recommended that developers rely more on open greenway designs rather than clustered open space designs and that the maintenance of these open spaces be privatized (i.e. under the control of homeowner associations or SID’s).

Proposed Follow-Up Research

1) Replicate these hedonic price models focusing on open space using only undeveloped lot sales. This would potentially be more helpful for residential housing developers to identify different profit levels associated with different open space designs

2) Surveys of homebuyers to elicit their perceptions of and preferences for different open space amenities. This could potentially confirm many of the conclusions reached in this study based on observed housing sale prices.

References

Chivers, J. and N. E. Flores. 2002. “Market Failure in Information. The National Flood Insurance Program.” *Land Economics*, 78(4):515-521

Dehring, C. and N. Dunse. 2006. “Housing Density and the Effects of Proximity to Public Open Space in Aberdeen, Scotland.” *Real Estate Economics.* 34(4) 553-566.

FEMA, 2007. Floodplain Premium Estimator. (www.floodsmart.gov)

Halvorsen, R., and R. Palmquist. (1980). “The Interpretation of Dummy Variables in Semilogarithmic Equations” *The American Economic Review*. 70(3) 474-475.

Irwin, E. G. 2002. “The Effects of Open Space on Residential Property Values.” *Land Economics.* 78(4) 465-480.

Kennedy. P. (1981). “Estimation with correctly interpreted Dummy variables in semi-logarithmic equations.” *American Economic Review*. 71(4), 801

Palmquist, R. B. (1984). “Estimating the Demand for Characteristics of Housing.” *Review of Economics and Statistics.* 64, 394-404.

Palmquist, R. (1991). “Hedonic Methods.” *In Measuring the Demand for Environmental Quality,* J.B. Braden and C.D. Kolstad. Elsevier Science Publishers. 78-120

Paterson, R. W. and K. J. Boyle. 2002. “Out of Sight, Out of Mind? Using GIS to Incorporate Visibility in Hedonic Property Value Models.” *Land Economics.* 78(3).

PMNRD, 2007. *New Flood Maps Show More in Harms Way.* Spectrum (Summer, 2007)

PMNRD, 2006. Deed of Trust Note (purchase agreement) between the PMNRD and Dial Corporation. March, 2006. 72 pages. (provided in PDF format by the PMNRD).

Qui, Z.Q., T. Prato, and G. Boehm, 2006. “Economic Valuation of Riparian Buffer and Open Space in a Suburban Watershed.” *Journal of the American Water Resources Association.* 42(6):1583-1596.

Shultz, S. and P. Fridgen. (2001). “Floodplains and housing values: Implications for flood mitigation projects.” *Journal of the American Water Resources Association.* 37(3), 595-603.

Shultz, S.D. and N.J. Schmitz. Forthcoming. “Augmenting Housing Sales Data to Improve Hedonic Estimates of Golf Courses.” *Journal of Real Estate Research.*

Shultz, S, and N. Schmitz, 2008 (accepted forthcoming). “Viewshed Analyses to Measure the Impact of Lake Views on Urban Residential Property Values.” *The Appraisal Journal* (Summer, 2008 Issue).

Nitrate stimulated oxidative dissolution of U(IV) bearing minerals leading to U mobility in Nebraska groundwater

Basic Information

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Descriptors:	
Principal Investigators:	Karrie Anne Weber, Daniel Davidson Snow

Publications

There are no publications.

2011 Project Report: Nitrate stimulated oxidative dissolution of U(IV) bearing minerals leading to U mobility in Nebraska groundwater

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Project Summary

Soluble uranium (U) is a recognized contaminant in public water supplies in various counties throughout the state of Nebraska. The mechanism driving U mobilization in these environments remains poorly understood. In order to begin to consider mitigation strategies and prevent further contamination of drinking water sources, it is necessary to gain a fundamental understanding of the mechanisms stimulating U mobilization. In the state of Nebraska U originated from the weathering of uranium-rich igneous rocks in the Rocky Mountains and deposited in shallow alluvial or ground water environments as insoluble reduced uranium minerals, such as uraninite and coffinite. These reduced U (U(IV)) minerals are subject to oxidation by available oxidants, such as oxygen and nitrate. The oxidation product exists primarily as a dissolved U(VI) species. It is well recognized that anthropogenic activities such as livestock operations and the application of N onto agricultural fields and urban landscapes have resulted in nitrate contamination of surface and groundwaters in the state of Nebraska. Abiotic and bio-oxidative dissolution of U(IV) coupled to nitrate reduction has been recently recognized as a potential U oxidative mechanism. Oxidative dissolution of U(IV) would result in the subsequent mobilization of U in groundwater. Thus, the influx of nitrate as a primary groundwater contaminant can subsequently influence U mobility resulting in a secondary contaminant in ground water through both biotic and abiotic mechanisms (Figure 1).

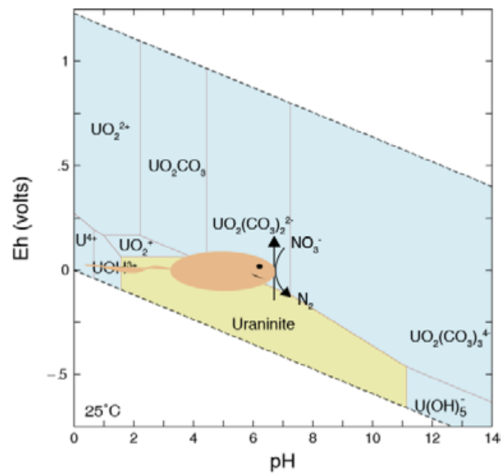

Fig. 1. Model of nitrate stimulated biotic uraninite oxidative dissolution.

The objective of this project was to examine the oxidative dissolution of U(IV) minerals coupled to the reduction of nitrate, according to the following working hypothesis: *Abiotic and biotic catalysis of nitrate-dependent uraninite and coffinite oxidation results in U mobility in Nebraska groundwaters*.

Project Results

Figure 2. Sediment core and groundwater collected from Alda, NE, (40.8299804 N, -98.5504021 W, elevation 1947 ft.) October 2009 in the Platte River Flood Plain.

A field site near Alda, NE (40.8299804 N, -98.5504021 W, altitude 3413 ft.) was selected for this study based on the prior data demonstrating aqueous U and nitrate in the groundwater (Figure 2) (Snow, 1996). While the prior study evaluated aqueous and total sedimentary U concentrations, it was unknown if U(IV)-bearing minerals were present in these sediments. In order to determine if U(IV) was present at this site, groundwater and sediment cores (20'-64' below surface) were collected and geochemically characterized. Groundwater pH revealed near neutral pH across 3 depths sampled (Figure 3A) and sediment pH ranged from ca. 5.5-7 (Figure 4A). The reduction potential (Eh) revealed a reducing environment across the three depths sampled (Figure 2B) and was confirmed by the presence of Fe(II) (Figure 4A). Although the subsurface environment was reduced, nitrate persisted in the groundwater to a depth of 60 ft. (Figure 2C). Nitrate concentrations were observed to decrease slightly from 38 mg/L (40 ft.) to 30 mg/L (50 and 60 ft) with increasing concentrations of Fe(II) and U(IV) (Figure 4B&C). Dissolved U, U(VI), significantly increased with depth from 30.3 μg/L (40ft) to values of 302 μg/L (60 ft) (Figure 3D), 10 times in excess of the maximum contamination level. The increase in dissolved uranium with depth parallels the increase in total uranium concentration with depth (Figure 3D and Figure 4C).

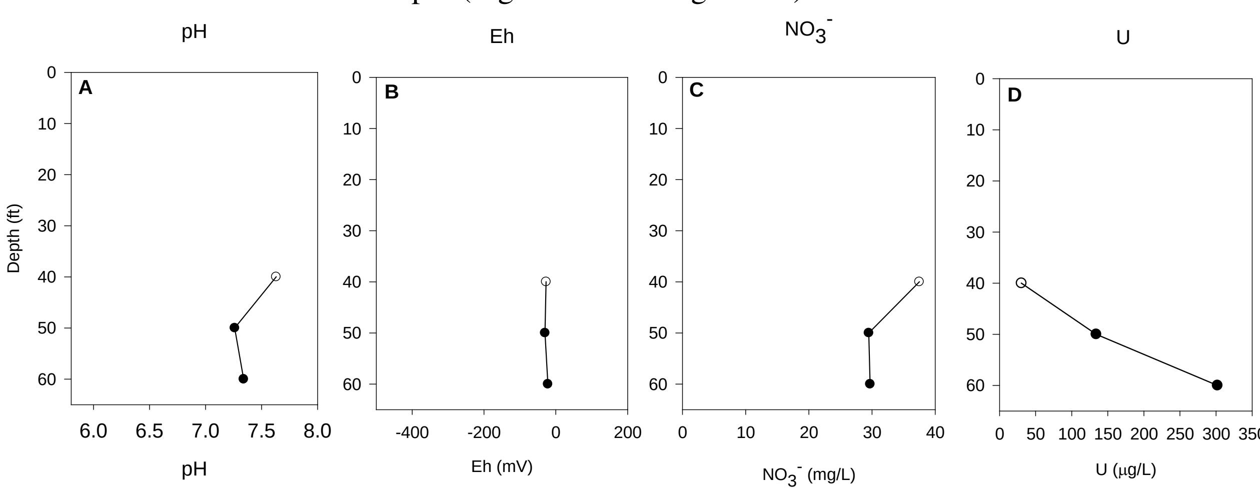

Figure 3. Groundwater geochemical data collected from Alda, NE, October 2009. A) pH, B) Eh, C) nitrate, and D) Total dissolved Uranium. Depth is reported as feet below ground surface.

While the presence of dissolved uranium is consistent with prior studies at this field site (Snow, 1996), these data alone do not indicate the presence of U(IV). Inductively coupled plasma mass spectroscopy (ICP-MS) analysis of sequentially extracted U(VI) and U(IV) was conducted as described by Elias and colleagues (Elias et al., 2003) in order to determine the valence state of the U. U(IV) concentrations in the sediments immediately above the water table, 22.5 ft., 18.7 ± 1.4 μg kg^{-1}, and at the water table, 23.5 ft., 15.0 ± 4.8 μg kg^{-1}, exceeded bicarbonate extractable U(VI) concentrations (2.4 ± 0.4 μg kg^{-1} and 1.6 ± 0.3 μg kg^{-1}, respectively). Virtually all of the U measured in the sediments existed as a U(IV) species (Figure 4C). The presence of U(IV) is consistent with reduced Fe (Fe(II)) (Figure 4B) as well as the low reduction potential observed in the groundwater (Figure 3B). Given the low reduction potential and that virtually all of the U in the sediments exists as a reduced phase, the increase in aqueous U concentrations with depth suggest that active U cycling may be occurring at this site. For active U geochemical cycling to occur, U must undergo oxidation and reduction reactions which can be biotically and abiotically driven.

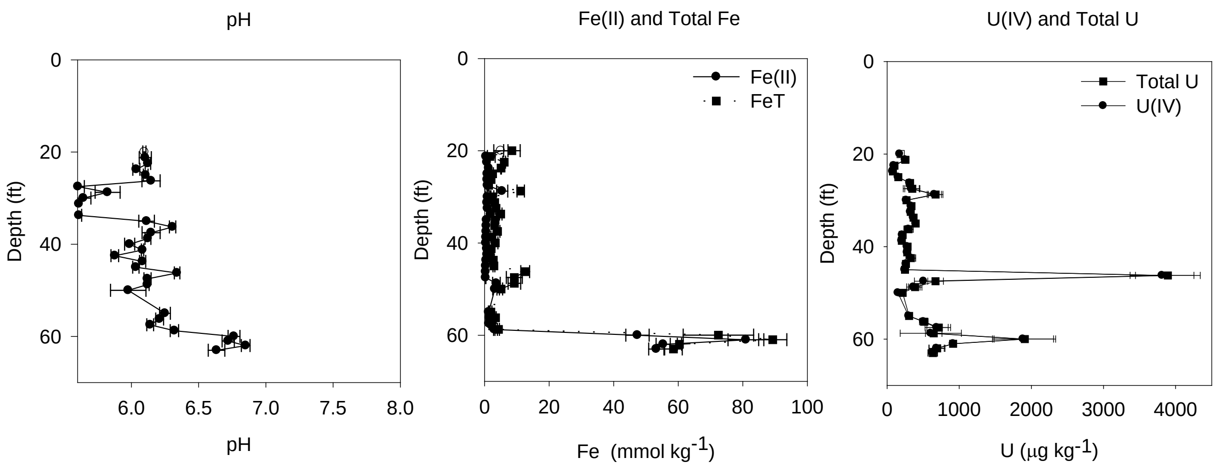

Figure 4. Sediment geochemical data collected from Alda, NE, October 2009. A) pH, B) acid-extractable Fe(II) and total Fe, and C) U(IV) and U(VI). Depth is reported as feet below ground surface.

Tetravalent U (U(IV)) phases are stable in reduced environments, however the input of an oxidant such as oxygen or nitrate into these systems would result in the oxidation and thus the mobilization of U. The increase in the reduction potential at different depths (data not shown) suggests significant heterogeneity and that portions of the aquifer contain oxygen, however groundwater geochemical data suggests that the aquifer is suboxic. It has been recognized in recent years that nitrate is a suitable U(IV) oxidant via abiotic or biotic mechanisms (Finneran et al., 2002; Senko et al., 2002; Beller, 2005). A recent study conducted by Moon and colleagues further indicated that the oxidation rate of U(IV) was greater in the presence of nitrate than in the presence of oxygen (Moon et al., 2007). Thus the presence of nitrate in this system suggests that nitrate could be a U(IV) oxidant in this subsurface system. Furthermore, microorganisms capable of oxidizing U(IV) in the presence of nitrate are taxonomically diverse and environmentally ubiquitous (Weber et al., in press). Prior research in our laboratory has identified these microorganisms in the top soil of an agricultural field in Nebraska (Weber et al., in press). Most probable number enumeration of nitrate reducing microorganisms demonstrated

that these microorganisms were abundant in the subsurface sediments collected ranging from 4.273×10^{3} to 2.4×10^{10} cells g^{-1} sediment. Enrichments were initiated in order to verify microbial U reduction and U oxidation coupled to nitrate reduction. Sediment slurries in artificial groundwater medium (10% mass/volume) were serially diluted and incubated over a period of eight weeks and compared to uninoculated controls. Oxidation (0-4,554 $\mu g\ L^{-1}$) and reduction (0-55 $\mu g\ L^{-1}$) of U exceeded uninoculated controls further providing evidence of a U biogeochemical cycling in these subsurface sediments. The oxidation of U(IV) could contribute to U immobilization in the groundwater and result in decreased water quality.
Not only could nitrate serve as an oxidant, but iron oxides could also contribute to U mobilization (Ginder-Vogel et al., 2009). Nitrate-dependent Fe(II) oxidation is an environmentally ubiquitous process facilitated by a diversity of microorganisms (Weber et al., 2006; Weber and Coates, 2007). While biogenic Fe(III) oxides have not been demonstrated to abiotically react with U(IV) minerals, additional research is necessary in order to establish if there is a role of biogenic Fe(III) oxides in U geochemical cycling. This microbially mediated process could also have a confounding effect on uranium mobility in subsurface environments including the Alda site located in Nebraska.

HPLC-ICP-MS Method Development. Uranium speciation experiments using ion exchange chromatography coupled to ICP-MS (Truscott, 2001) have been developed. On-line ion exchange chromatography coupled directly to an inductively coupled plasma mass spectrometer (IC-ICPMS) provides a method to distinguish between oxidized reduce forms of uranium in solution. Uranium(IV) is separated from U(VI) with an IonPac CG10 cation column and dilute nitric acid mobile phase on a GV Platform XS ICPMS (Figure 6). Hexavalent uranium U(VI) was reduced in 1M hydrochloric acid solution with titanium trichloride to prepare U(IV) standards and immediately analyzed by HPLC-ICP-MS (Sill, 1980). Both reduced and oxidized forms can be analyzed in the same solution and confirm the presence and relative concentrations of the extracted oxidized and reduced uranium species.

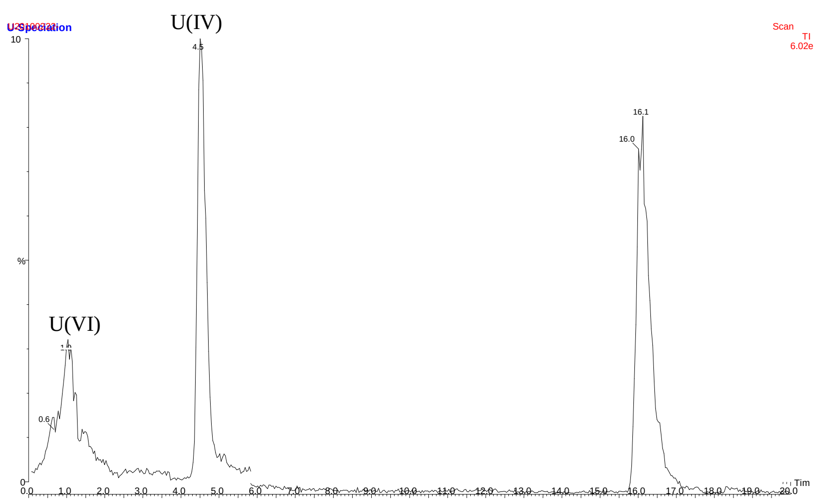

Figure 6. Chromatogram of acid extracted U(IV) and U(VI) separated with an IonPac CG10 cation column and dilute nitric acid mobile phase on a GV Platform XS ICPMS.

Results Summary

To date the data that we have gathered has allowed us to establish a basis as well as identify an appropriate field site for future research to continue to investigate the abiotic and biotic catalysis of U(IV) oxidation and the subsequent significance to U mobility in Nebraska groundwaters. Additionally this preliminary research has also led to the development of a method to allow the simultaneous measurement of U(IV) and U(VI) in solid samples via HPLC-ICP-MS. We expect the additional modifications to the preliminary method will result in a technique that can be used to easily quantify U(IV) in sedimentary systems. The data we have obtained to date as well as the data we will continue to collect has provided us with valuable information in order to begin to understand the mechanisms driving U mobilization in Nebraska groundwaters.

References Cited

Beller, H.R. (2005) Anaerobic, Nitrate-Dependent Oxidation of U(IV) Oxide Minerals by the Chemolithoautotrophic Bacterium *Thiobacillus denitrificans*. *Appl Environ Microbiol* **71**: 2170-2174.

Elias, D.A., Senko, J.M., and Krumholz, L.R. (2003) A procedure for quantitation of total oxidized uranium for bioremediation studies. *J Microbiol Methods* **53**: 343-353.

Finneran, K.T., Housewright, M.E., and Lovley, D.R. (2002) Multiple influences of nitrate on uranium solubility during bioremediation of uranium-contaminated subsurface sediments. *Environ Microbiol* **4**: 510-516.

Ginder-Vogel, M., Stewart, B., and Fendorf, S. (2009) Kinetic and Mechanistic Constraints on the Oxidation of Biogenic Uraninite by Ferrihydrite. *Environmental Science & Technology* **44**: 163-169.

Liu, Z., Lozupone, C., Hamady, M., Bushman, F.D., and Knight, R. (2007) Short pyrosequencing reads suffice for accurate microbial community analysis. *Nucl Acids Res* **35**: e120.

Moon, H.S., Komlos, J., and Jaffe, P. (2007) Uranium reoxidation in previously bioreduced sediment by dissolved oxygen and nitrate. *Environ Sci Technol* **41**: 4587-4592.

Senko, J.M., Istok, J.D., Suflita, J.M., and Krumholz, L.R. (2002) In-Situ Evidence for Uranium Immobilization and Remobilization. *Environ Sci Technol* **36**: 1491-1496.

Sill, C.W. (1980) Determination of gross alpha, plutonium, neptunium, and/or uranium by gross alpha counting on barium sulfate. *Analytical Chemistry* **52**: 1452-1459.

Snow, D.D. (1996) Geochemistry, Hydrology, and Environmental Applications of Uranium-Series Nuclides in the Platte River Drainage Basin. In *Department of Geology*. Lincoln: University of Nebraska, p. 159.

Truscott, J., Jones, P., Fairman , B., and Evansa, E. (2001) Determination of actinides in environmental and biological samples using high-performance chelation ion chromatography coupled to sector-field inductively coupled plasma mass spectrometry. *J Chromatography A* **928**: 91-98.
Weber, K.A., and Coates, J.D. (2007) Microbially-Mediated Anaerobic Iron(II) Oxidation at Circumneutral pH. In *Manual of Environmental Microbiology*. Hurst, C.J., Crawford, R.L., Garland, J.L., Lipson, D.A., Mills, A.L., and Stetzenbach, L.D. (eds): ASM Press.

Weber, K.A., Achenbach, L.A., and Coates, J.D. (2006) Microorganisms pumping iron: anaerobic microbial iron oxidation and reduction. *Nat Rev Microbiol* **4**: 752-764.

Weber, K.A., Thrash, J.C., Van Trump, J.I., Achenbach, L.A., and Coates, J.D. (in press) Environmental and Taxonomic Bacterial Diversity of Anaerobic Uranium(IV) Bio-Oxidation *Appl Envir Microbiol*.

Towards groundwater recharge forecasting: monitoring and modeling episodic recharge responses to weather events

Basic Information

Title:	Towards groundwater recharge forecasting: monitoring and modeling episodic recharge responses to weather events
Project Number:	2010NE199B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	1
Research Category:	Climate and Hydrologic Processes
Focus Category:	Groundwater, Climatological Processes, None
Descriptors:	
Principal Investigators:	John Barrett Gates

Publications

There are no publications.

Technical Report: USGS 104b

Towards groundwater recharge forecasting: monitoring and modeling episodic recharge responses to weather events

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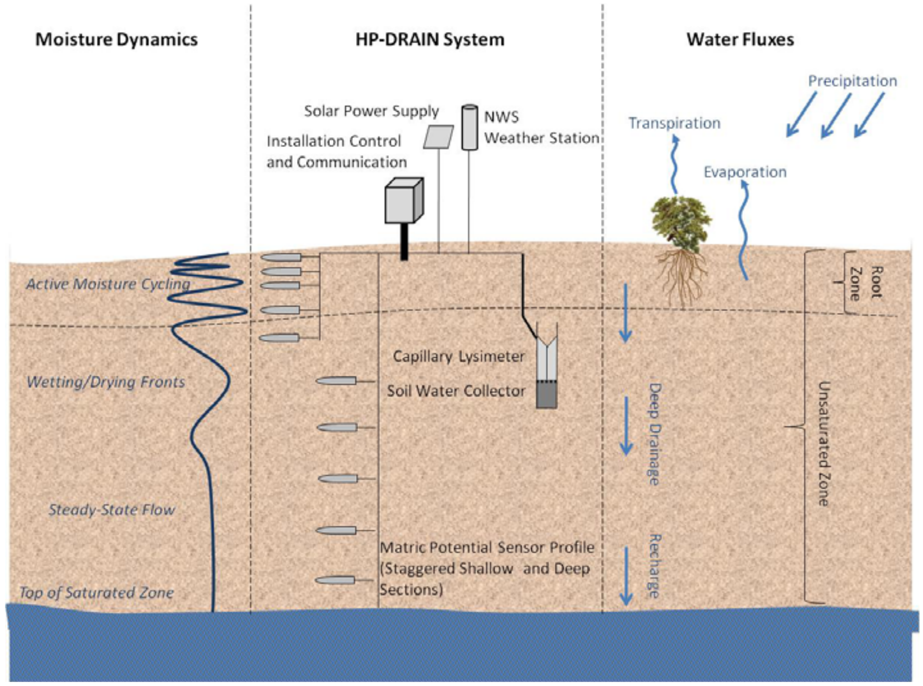
Problem: Because it is the process by which underground aquifers are replenished, groundwater recharge is central to water resource considerations. Nebraska's agricultural sector has benefited from naturally high recharge rates across much of the state. However, some areas particularly in western Nebraska (Box Butte, Perkins, Chase and Dundy Counties) have experienced long-term water table declines, and several Natural Resources Districts have declared their water resources to be fully appropriated. A clear understanding of recharge is important to assess groundwater inputs and develop reliable groundwater availability models for planning purposes. However, Reliable recharge information remains scarce despite the central role of recharge in groundwater renewability. Critically, little is known about the intermittent drainage processes that are responsible for generating recharge under semi-arid climate conditions (e.g., episodic recharge generation). While the occurrence of episodic recharge is well established, a knowledge gap persists about how discrete events combine to constitute a long-term average because of the lack of quantitative deep drainage measurements and relatively short periods of record. The resulting data vacuum is often filled by recharge estimates derived from the residual of other terms in the terrestrial water balance, or as a calibration parameter in groundwater flow simulations. While these estimates may be practical in some cases, they are subject to a high degree of uncertainty and are not capable of determining how recharge rates will respond to changing rainfall inputs.

Research Objectives: Particularly in semi-arid regions, there is abundant evidence that precipitation event-scale hydrologic processes are important factors affecting recharge rates. However, very little information is available about relationships between episodic recharge events and storm events under field conditions. The goal of the proposed project is to develop a method of assessing groundwater recharge on the timescale of individual rainfall events. Intended outcomes include a determination of the meteorological characteristics of storm events that contribute to groundwater recharge in Nebraska, and an assessment of the feasibility of predicting distributed groundwater recharge from radar.

Methodology: The project combines research tools from hydrology and meteorology to assess relationships between rainfall and recharge. We established an unsaturated monitoring site within the Gudmundsen Sandhills Laboratory near Mullen NE (Fig 1a). We installed one matric potential monitoring profile using 8 sensors (Campbell Scientific 229-L) deployed at depths 0.5-8 m. The sensors were individually calibrated in the PI's laboratory (dT versus matric potential curves quantified using pressure plate extractors) in order to maximize precision. Sensors were installed into a 2" diameter hole that was backfilled with silica flour around the sensors (to promote rapid moisture equilibration with the surrounding sediments) and layers of bentonite shot in between sensor positions (in order to prevent preferential flow along the profile; Fig 1b). Topsoil was carefully excavated and replaced with minimal disturbance to vegetation around the site. We also installed one passive lysmeter (Decagon Drain Gauge) at the site. The top of the divergence control tube was placed at 2 m depth in order to ensure that drainage rates that are measured are representative of conditions below the root zone. Both systems were connected to a solar-powered data logger (Campbell CR1000 with AM-16 multiplexer). The site is on the same dune as a National Weather Service weather station which extremely high quality weather data for the rainfall/recharge comparisons. All instrumentation is now in place and collecting the necessary data to complete the project. This robust monitoring station is expected to be operational for several years based on the PI's past experience.



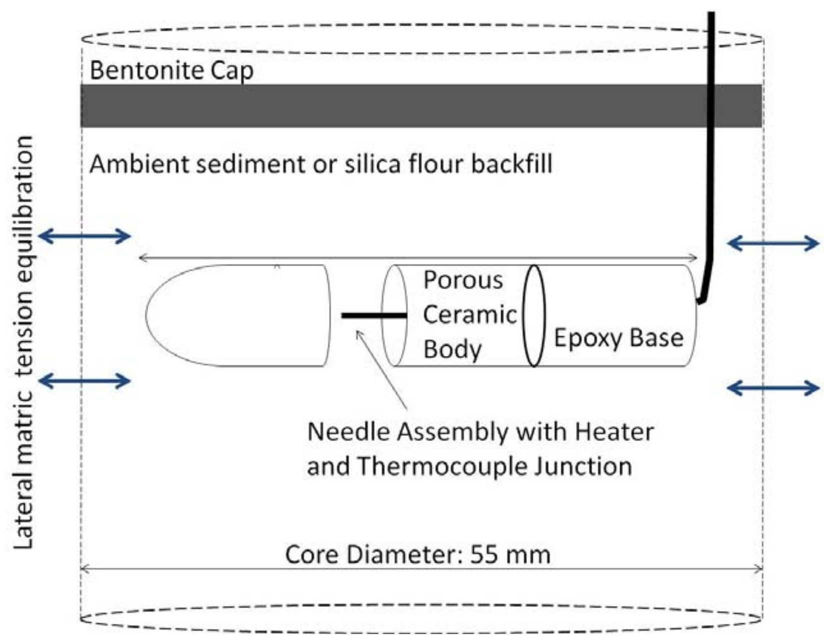


Fig 1a and 1b. Monitoring system configuration.

Our next step is to model this system using WSR-88D radar data as inputs. We secured departmental funding for a Master's student to work on this project (co-supervised by Gates and Houston beginning in Fall 2010), and she will undertake this task for her thesis project. Her work is focusing on assessing and improving the accuracy of radar-driven recharge models. Gates is also supervising a related undergraduate research project funded by UNL's UCARE program. The undergraduate project is using chemical tracer-based recharge estimation methods at the monitoring site. Through this work we will be comparing tracer and physical monitoring recharge assessment methods.

Principal Findings:

We have made preliminary assessments of recharge rates using approximately 6 months of lysimeter data. We have generated tracer-based comparisons for this data set using 1) isotope displacement and 2) chloride mass balance. We have created a 1-D unsaturated zone flow model for the monitoring site based on soil water retention properties and vegetation. We are currently comparing these estimates with hypothetical boundary conditions using the unsaturated zone flow model. We do not yet have one full annual cycle of unsaturated zone data to model because the 229-L sensors have taken several months to equilibrate (despite our efforts to specially prepare the sensors in order to minimize the length of equilibration period). We anticipate that a 12 month comparison between the radar-driven model and unsaturated zone data will be completed in 2011.

Investigating a New and Potentially Critical Cyanobacterial Toxin in Midwestern Reservoirs

Basic Information

Title:	Investigating a New and Potentially Critical Cyanobacterial Toxin in Midwestern Reservoirs
Project Number:	2010NE201B
Start Date:	3/1/2010
End Date:	2/28/2011
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Congressional District:	1
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Kyle D. Hoagland

Publication

1. Maitham A. Al-Sammak, Daniel D. Snow, and Kyle D. Hoagland. 2011. BMAA in Eutrophic Reservoirs in the Midwestern U.S. (Abstract) Proc. 1st Ann. World Cong. Mar. Biotech., Dalian, China. pg. 257.

Introduction

Algae are photosynthetic microorganisms that play an important role in the functioning of aquatic ecosystems, in that they are the principal primary producers that form the base of aquatic food webs. Several groups of algae are capable of producing toxins that can impact aquatic ecosystems, especially managed systems. Cyanobacteria rank the most important of these in freshwaters; several of its members produce a variety of toxins (termed cyanotoxins), including hepatotoxins, and neurotoxins. Here, we focus on the potent neuro-cyanotoxin BMAA (β-methylamino-L-alanine), which has recently been shown to cause several neurodegenerative disease in humans in several parts of the world (e.g., Guam, China) (Cox et al. 2003;). Biomagnification of BMAA via the food chain is a recently studied process of potentially great relevance to both human and animal health (Purdie et al. 2009, Bidigare et al. 2009, Brand 2009). Because cyanobacteria are widespread in freshwater systems and BMAA release is widespread among them, BMAA could be found in many freshwater systems, resulting in a potentially important human exposure risk.

BMAA-related generative diseases include: amyotrophic lateral sclerosis (ALS or Lou Gehrig's disease), Parkinson's disease, and Alzheimer's disease. In 2003, it was first discovered that cyanobacteria of the genus *Nostoc*, which live as endosymbionts in the roots of a local cycad, produced BMAA (Cox et al. 2003). In 2005, several diverse genera of cyanobacteria, including both symbiotic and free-living species, were found to produce BMAA (Cox et al. 2005). Because BMAA concentrates in the developing reproductive tissue of the cycad, free-living cyanobacteria can produce 0.3ug/g BMAA, or up to 2-37ug/g as symbionts in the coralloid roots of cycads. In one well-known study, it was determined that those members of the Chamorro people on Guam that consumed the cycad seeds suffered from ALS or the Parkinson-dementia complex (PDC), which ultimately killed approximately 10% of Guam's indigenous Chamorro population. The traditional cuisine of the Chamorro people has also included fox bats, which feed on cycad flowers and "fruits." Thus, it has been suggested that "the plant and animal proteins provide unrecognized reservoirs for the slow release of this toxin." (Banack and Murch 2009, Cheng and Banack 2009, Murch et al. 2004)).

BMAA was also recently found in the brain tissue of nine Canadian Alzheimer patients, thus BMAA-induced neurodegeneration is likely a more widespread phenomenon than originally thought. This suggests the existence of alternative ecological pathways for the bioaccumulation of BMAA. BMAA has subsequently been detected in cyanobacterial blooms and laboratory isolates from marine and freshwater sources from varied localities worldwide including: Iraq, Qatar, Hawaii, China, United Kingdom, South Africa, Netherlands, and Sweden (Bradley and Mash 2009, Faassen et al. 2009, Li et al. 2010, Cox et al. 2010, Esterhuizen 2008). As a result, it has been hypothesized that BMAA might occur and bioaccumulate in other ecosystems as well. Studies have shown that BMAA levels are higher in zooplankton, which can feed on cyanobacteria. Even higher BMAA levels were found in some fish species examined (Jonasson et al. 2010), suggesting a bioaccumulation of BMAA. A particularly remarkable finding was the discovery of high BMAA levels in bottom-dwelling fish species (*S. maximus, T. quadricornis, and O. eperlanus*) and in water filter-feeding mollusks (*M. edulis and O. edulis*).

Therefore, the overall objectives of our research were to: (1) develop the methodology necessary to detect this single amino acid at very low, µg/L levels, in open water as well as in macrophyte and fish tissues, (2) better understand the ecological factors that may be involved in the release of BMAA, and (3) ascertain the potential routes of exposure of BMAA in humans relative to freshwater systems. Here we present findings which address parts of objectives one and three, including the first report of BMAA in open water in the U.S.

Materials & Methods

Grab samples were collected in September and October in 2009 and 2010, from ten reservoirs that had a history of cyanotoxins problems in Nebraska (based on their microcystin levels and associated Health Advisory Alerts) and two reservoirs (Branched Oak and East Twin) that did not have a history of cyanobacteria blooms (since 2004), to essentially serve as controls. Samples were collected from 2-3 sites in each reservoir, by submerging a clean plastic wide-mouth bottle at the surface, just beneath the surface, and near the bottom at each site, then compositing these samples for each site. Samples were returned to the lab in a cooler, then freeze-dried overnight, ground into a fine powder, extracted in 1 mL of 0.1 N TCA at 4 C for 16 h using MCX-Waters, and centrifuged to form a pellet (with bound BMAA) and a supernatant fraction (with free BMAA).

BMAA analytical methods included:

1) Toxin samples were derivatized using AQC; to each 500 µl of extracted sample we added 250 µl of 5% borate buffer, mixed well, and derivatized with 50 µl of AQC (6-aminoquinolyl-N-hydroxysuccinimidyl carbamate), and again mixed well. The mixture was allowed to react for 15-30 min, then transferred in a filter HPLC vial to be analyzed with HPLC;

2) Detection methods included HPLC/FD: cyanotoxins were separated using reverse-phase elution (Kromasil-Thermohypersil C8 column, 4.6 x 250 mm) on a Water HPLC Alliances 2695, and a Water Autosampler using a gradient method with 140 mM ammonium acetate, 5.6 mM triethylamine, pH 5.7 in water, and 52% acetonitrile in water at 40O C, a flow rate of 1.0 ml/min, and 20 µl of sample injection. Algal toxin concentration was quantified by detection of the fluorescent tag (Water 2475 Multi **λ**-Fluorescence Detector) with excitation at 250 nm and emission at 395 nm .

Results

Data summarized in Table 1 show the presence of BMAA, as well as other neurotoxins produced by cyanobacteria, in open water grab samples from 12 reservoirs sampled over the two-year period from 2009-2010. BMAA levels ranged from 6.0 µg/L in Holmes Lake, a small municipal reservoir within Lincoln, to 25.3 µg/L in Kirkman's Cove Reservoir, a shallow, polymictic reservoir located km southeast of Lincoln, Nebraska in a row-crop agricultural area. BMAA was detected in 6 of the 10 reservoirs with histories of cyanobacterial blooms and associated microcystin levels above the state standard of 20 µg/L. BOAA and DABA were detected in lower concentrations, with BOAA found in measureable quantities in just one reservoir (Kirkman's Cove, at 4.9 µg/L), whereas DABA was found in 7 sites, ranging from 12.7 µg/L in Pawnee Reservoir to 21.1 µg/ L in Willow Creek Reservoir. Anatoxin-a, also a powerful neurotoxin, was detected in 8 of the 10 reservoirs with a predominance of cyanotoxins. Microcystin was found in all but the control reservoirs, with concentrations ranging from 5.9 to 44.5 µg/L. The highest level occurred in Rockford Reservoir, which also had the second highest BMAA level and the highest DABA concentrations found.

Table 1. Cyanobacterial neurotoxin levels in open water grab samples from 2009 and 2010 (BOAA = L-3-oxalylamino-2-amino-ppropionic acid, and; DABA = DL-2,4-diaminobutyric acid dihydrochloride, an isomer of BMAA). All concentrations are in µg/L (ppb). Detection limits were 5.0 µg/L for BMAA, 4.3 for BOAA, 7.0 for DABA, 6.0 for anatoxin-*a*, and 5.0 µg/L for microcystin†.

Reservoir	**Location (NE County)**	**Dates Sampled* (number of samples)**	**BMAA 2009/10**	**BOAA**	**DABA**	**Anatoxin -*a***	**Microcystin †**
Holmes Lake	Lancaster	9.7.09(3)/8.6.10(3)	6.0/0	0/0	BDL/0	5.0/0	BDL/BDL
Pawnee	Lancaster	10.28.09(2)/8.20.10(3)	11.3/BDL	BDL/0	12.7/0	14.4/BDL	11.0/5.9
Wagon Train	Lancaster	10.6.09(3)/10.26.10(3)	0/0	0/0	0/0	0/0	BDL/BDL
Stage Coach	Lancaster	10.7.09(3)/10.26.10(3)	0/0	0/0	0/0	0/0	0/0
East Twin	Seward	10.9.09(3)/10.25.10(3)	0/0	0/0	0/0	0/0	0/0
Rockford	Gage	8.3.09(2)/8.22.10(3)	24.5/18.3	BDL/0	13.2/13.6	8.4/BDL	44.5/11.9
Kirkman's Cove	Richardson	8.3.09(2)/8.8.10(3)	BDL/25.3	0/4.9	BDL/14.7	35.0/BDL	14.8/35.0
Swan Creek	Saline	9.10.09(2)/9.9.10(3)	BDL/BDL	0/0	BDL/BDL	BDL/BDL	6.3/21.0
Conestoga	Lancaster	10.8.09(03)/8.23.10(3)	0/0	0/0	0/0	0/0	7.8/BDL
Willow Creek	Pierce	8.30.09(2)/10.1.10(3)	0/12.6	0/BDL	0/21.1	0/16.1	15.1/35.0
Branched Oak	Lancaster	9.20.010(2)/9.20.10(3)	0/0	0/0	0/0	0/BDL	BDL/BDL
Bluestem	Lancaster	9.25.09(2)/9.8.10(3)	0/0	0/0	0/BDL	0/BDL	18.3/BDL

0 = None Detected; BDL = Below Detection Limit (i.e. the toxin was detected but could not be reliably quantified); *in MM.DD.YR format; † data from Nebraska Department of Environmental Quality (ELISA kit method)

The general lack of a strong correlation between the level of microcystin and BMAA is not surprising in light of the likely differences in the fate and transport, and potential for bioaccumulation of these two neuro-cyanotoxins. However, it is important to note that in instances where microcystin was found at higher concentrations (>20 µg/L), BMAA also typically occurred (i.e. 75% of all 2009-10 samples) at levels well above the detection limit, indicating that there is a reasonable probability that reservoirs for which a Health Alerts are issued are likely to also have detectable levels of BMAA present in the water column. Indeed, in reservoirs with heavy neuro-cyanotoxin loads (including microcystin and BMAA), such as Rockford, Pawnee, Willow Creek (in 2010) and Kirkman's Cove Reservoirs, that both DABA and anatoxin-*a* were most likely to be present as well. BOAA was the exception to this trend, as it was found in only one sample in 2010, although it also occurred in Kirkman's Cove Reservoir.

Discussion

This is the first report of BMAA found in open water samples. (The highest level found, 25.3 µg/L, may be of concern with respect to the human health risk, particularly in light of its potential to biomagnify in the environment. Currently, no MCL currently exists for BMAA, its isomer DABA, or for any other neuro-cyanotoxins which are likely to occur in many eutrophic lakes and reservoirs worldwide. In light of its neurodegenerative potential, BMAA and other neurotoxins may need to be included in routine monitoring and with respect to reservoir management. Particularly in reservoirs with histories of severe cyanobacterial blooms, fish tissue monitoring may also be considered along with monitoring lake water neurotoxin and microcystin levels, in order to avoid long-term impacts on human health. Future research should focus on determining the extent to which BMAA biomagnifies in freshwater systems and the practical limits of exposure allowable, based on mammalian models. In addition, we need a better understanding of the ecological clues involved in neuro-cyanotoxin production as well much better information on other potential routes of exposure to BMAA, such as aerial (dust) exposure (Cox et al. 2009), as well as exposure via cyanobacterial contaminated foods (e.g., Jonasson et al. 2010, Faassen et al.. 2009, Roney et al. 2009). Finally, future studies should also focus on the combined effects of two or more neuro-cyanotoxins, because exposure in nature will typically involve mixtures of these compounds, which may act antagonistically or additively, as has been shown for pesticide exposures for example (Lobner 2009, Carder and Hoagland 1998).

Summary & Conclusions

As a result of agricultural inputs and naturally nutrient-rich soils, cyanobacterial blooms are a common occurrence in Midwestern reservoirs. BMAA is a new and powerful neurotoxin produced by all cyanobacteria tested thus far in both freshwater and marine environments. It has the potential to bioaccumulate in many different species including fish, aquatic and terrestrial plants and animals, and in humans, potentially leading to severe and debilitating neurodegenerative diseases including ALS and PDC. Thus, there is still much to be learned about BMAA, its role in the environment and the risks that it may pose to humans in other countries outside of Guam, within the broader context of water resources management. Multidisciplinary teams scientists, including epidemiologists, ecologists, toxicologists, and sociologists will be needed to help solve and mitigate this relatively new environmental threat.

Literature Cited

Banack, S., and Murch, S. (2009). Multiple neurotoxic items in the Chamorro diet link BMAA with ALS/PDC. Amyotroph Lateral Sclerosis. 10, Suppl 2:34-40.

Bradley, W., and Mash, D. (2009) Beyond Guam: The cyanobacteria/BMAA hypothesis of the cause of ALS and neurodegenerative diseases. Amyotroph Lateral Sclerosis. 10, Suppl 2: 7-20.

Carder, J. and Hoagland, K. (1998). Combined effects of alachlor and atrazine on benthic algal communities in artificial Streams. Environmental Toxicology & Chemistry 17:1415-1420.

Cheng, R., and Banack, S. (2009). Previous studies underestimate BMAA concentrations in cycad flour. Amyotroph Lateral Sclerosis. 10, Suppl 2: 41-43.

Cox, P., Richer, R., Metcalf, J., Banack, S., Codd, G., and Bradley, W. (2009). Cyanobacteria and BMAA exposure from desert dust: a possible link to sporadic ALS among Gulf War veterans. Amyotroph Lateral Sclerosis. 10, Suppl 2: 109-117.

Esterhuizen, M., and Downing, T. (2008). Beta-N-methylamino-L-alanine (BMAA) in novel South African cyanobacterial isolates. Ecotoxicology & Environmental Safety 71:309-13.

Faassen, E., Gillissen, F., Zweers, H., and Lurling, M. (2009). Determination of the neurotoxins BMAA (beta-N-methylamino-L-alanine) and DAB (alpha-,gamma-diaminobutyric acid) by LC-MSMS in Dutch urban waters with cyanobacterial blooms. Amyotroph Lateral Sclerosis. 10, Suppl 2: 79-84.

Jonasson, S., Eriksson, J., Berntzon, L., Spacil, Z., Ilag, L., Ronnevi, L., Rasmussen, U., and Bergman, B. (2010). Transfer of Cyanobacterial neurotoxin within a temperate aquatic ecosystem suggests pathways for human exposure. Proceedings of the National Academy of Sciences. 107: 9252–9257.

Li, A., Tian, Z., Li, J., Yu, R., Banack, S., and Wang, Z. (2010). Detection of the neurotoxin BMAA within cyanobacteria isolated from freshwater in China. Toxicon. 55:947-53.

Lobner, D. (2009). Mechanisms of beta-N-methylamino-L-alanine induced neurotoxicity. Amyotroph Lateral Sclerosis. 10, Suppl 2: 56-60.

Murch, S., Cox, P., and Banack, S. (2004). A mechanism for slow release of biomagnified cyanobacterial neurotoxins and neurodegenerative disease in Guam. Proceedings of the National Academy of Sciences. 101:12228-122231.

Purdie, E., Metcalf, J., Kashmiri, S., and Codd, G. (2009). Toxicity of the cyanobacterial neurotoxin beta-N-methylamino-L-alanine to three aquatic animal species. AmyotropLateral Sclerosis. 10, Suppl 2:67-70.

Roney, B., Renhui, L., Banack, S., Murch, S., Honegger, R., and Cox, P. (2009). Consumption of fa cai *Nostoc* soup: a potential for BMAA exposure from Nostoc cyanobacteria in China? Amyotroph Lateral Sclerosis. 10, Suppl 2: 44-49.

Mitigate and Treat Antibiotic Residues and Antibiotic Resistance Genes in Soil and Water

Basic Information

Title:	Mitigate and Treat Antibiotic Residues and Antibiotic Resistance Genes in Soil and Water
Project Number:	2010NE207B
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End Date:	2/28/2011
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Congressional District:	1
Research Category:	Water Quality
Focus Category:	Waste Water, Treatment, Agriculture
Descriptors:	antibiotic, antibiotic resistance, livestock lagoon
Principal Investigators:	Xu Li, Daniel Davidson Snow

Publications

There are no publications.

2010 Project Report: Mitigate and Treat Antibiotic Residues and Antibiotic Resistance Genes in Soil and Water

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PROJECT SUMMARY

Antibiotics administered to livestock are often not completely absorbed or metabolized by the animals and are subsequently excreted through feces and urine. Thus, livestock waste lagoons become reservoirs of antibiotic residues and bacteria containing antibiotic resistance genes (ARGs). Despite their potential environmental impacts, the occurrence and fate of antibiotics and ARGs in lagoons are largely unknown. In this study, efforts were made to identify key environmental factors that determine the occurrence and fate of antibiotic residues and ARGs in lagoons. Liquid and sediment samples were collected from multiple beef and swine lagoons. ARGs rendering resistance to two families of antibiotics, tetracyclines and sulfonamides, were quantified using quantitative polymerase chain reaction (qPCR) and normalized to the 16S rRNA genes. Antibiotics were extracted from samples and measured using liquid chromatography tandem mass spectrometry. Correlations between ARGs, antibiotics, and other water quality parameters were determined using the Pearson correlation coefficient (r).

The total concentrations of each family of antibiotics, tetracyclines and sulfonamides, were both less than 10 ng/mL in the liquid samples. The total concentration of the tetracycline compounds tested (i.e. chlortetracycline (CTC), oxytetracycline (OTC), and tetracycline (TC)) ranged from 50.6 to 8907.7 ng/g in the lagoon sediment samples, while the total concentration of the sulfonamide compounds tested (i.e. sulfamethoxazole (SMXZ), sulfamethazine (SMTZ), sulfachloropyridazine (SCZ), sulfadimethoxine (SMX), sulfamerazine (SMRZ), sulfamethazole (SMZ), and sulfathiazole(STZ)) was lower than 5 ng/g in all lagoon sediment samples. Normalized ARG values ranged from 1.17×10^{-4} for *tet(D)* to 1.38×10^{-1} for *tet(Q)*. The correlation between ARGs and their corresponding antibiotics was not universally observed in the lagoon samples. In lagoon sediments, out of the four *tet* genes tested (i.e. *tet(D), tet(O), tet(Q)* and *tet(X)*), only *tet(O)* showed a strong positive correlation with CTC, OTC, TC, and total tetracycline (r>0.94, p<0.05). Neither of the two *sul* genes tested, *sul(I)* and *sul(II)*, exhibited statistically significant correlation with SMTZ, SMX, or total sulfonamide (p>0.05). Some water quality parameters, such as oxidation reduction potential (ORP), ammonia, and total suspended solid (TSS), were positively correlated with at least two ARGs. Other water quality parameters, such chemical oxygen demand (COD), total phosphorous (TP), orthophosphate phosphorous (OP), and volatile solids (VS), showed no statistically significant correlations with the occurrence of any ARG.

INTRODUCTION AND OBJECTIVES

Some recent studies reported the occurrence of antibiotic residues and ARGs in the environment. Most of these studies were focused on either the antibiotic residues or the ARGs, but rarely on both classes of contaminants. There have been even fewer studies aiming at designing mitigation processes to minimize both antibiotic residues and ARGs in the soil and water environments. Therefore, the ultimate goal of this study was to identify environmental factors that determine the fate and transport of both classes of contaminants in the environment and to design mitigation processes that can minimize the proliferation of both classes of contaminants in agricultural fields. Due to the time constraint, this study was focused on identifying key environmental factors that determine the occurrence and fate of antibiotics and ARGs in animal waste lagoons. The following objectives were established.

1. Quantify ARGs in the water and sediment of multiple livestock lagoons.
2. Quantify antibiotic residues in the water and sediment of multiple livestock lagoons
3. Measure other water quality parameters of the lagoon liquid
4. Search for correlations of antibiotic residues and ARGs with various environmental factors associated to livestock lagoons

EXPERIMENTAL METHODS

Sampling Site

The sampling site is at the USDA Meat Animal Research Center (MARC) in Clay Center, Nebraska. Two lagoon systems were sampled, one located at a beef cattle facility and the other located at a swine facility. The beef lagoon system was composed of four individual lagoons (i.e., multiple-stage lagoon) that are connected with culverts (Figure 1). The swine lagoon system was also made of four individual lagoons. One of swine lagoons was off-line at the time of sampling. Liquid samples were collected 1 foot underneath water surface in all lagoons. For lagoons that contained deep water at the time of sampling (i.e., B2, S1, S2, and S3) liquid samples were also collected 5 or 6 ft below water surface. Sediment samples were also collected from each lagoon. Records show that several tetracyclines and sulfanomides were administered to the livestocks at MARC by direct feeding or injection when animals were sick: CTC, OTC, and SMX for beef cattle, and CTC, OTC, TC and SCZ for swine.

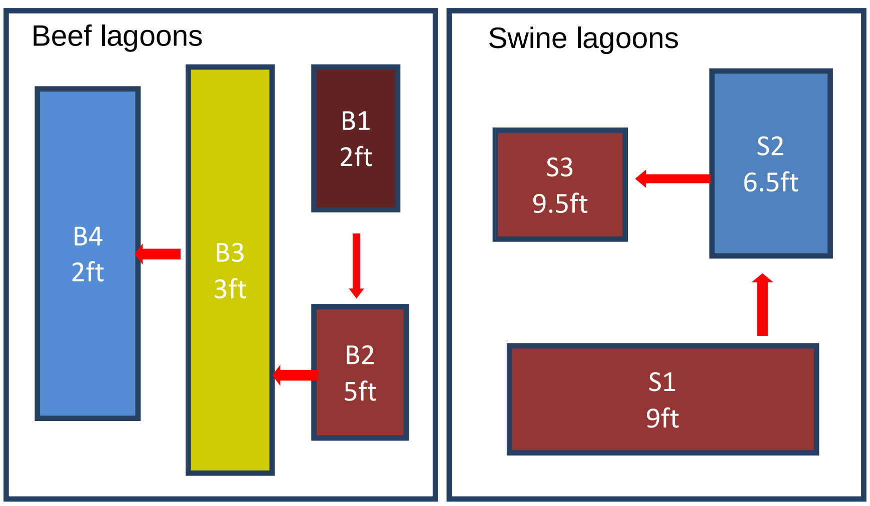

Figure 1. The layouts of the lagoon systems employed at the cattle and swine facilities at MARC. “B” and “S” stand for beef and swine lagoons, respectively. The numbers in each box represent the water depth of the individual lagoon.

Water quality and Microbial Analyses

Conductivity and ORP were measured on-site. Other water quality measurements, including chemical oxygen demand (COD), ammonia, nitrate/nitrite, sulfate, chloride, total phosphorous (TP), orthophosphate (OP), total solids (TS), volatile solids(VS), total suspended solids (TSS), Zn and Cu, were conducted in the UNL Environmental Engineering laboratory and the UNL Water Sciences Laboratory. Seventeen antibiotics covering commonly used tetracycline, sulfonamide, macrolide, and other antimicrobial compounds were analyzed using on-line solid phase extraction liquid chromatography-tandem mass spectrometry (LC/MS/MS) with detection limits ranging from 5 to 20 ng/L (ppt). The antibiotic resistance genes were quantified using qPCR reactions. A typical qPCR reaction had a volume of 20 µL, and contained optimal concentration of primer and 9 μL 2.5×RealMasterMix SYBR ROX/20 SYBR Solution (5 Primer, Gaithersburg, MD) and 4 ng of template DNA. qPCR conditions were adopted from published protocols: *tet(D)* (Fan *et al.* 2007), *tet(O)* (Pei *et al.* 2006), *tet(Q)* (Aminov *et al.* 2001), *tet(X)* (Ghosh *et al.* 2009), *sul(I)* and *sul(II)* (Pei *et al.* 2006), and the 16S rRNA gene (Suzuki *et al.* 2000).

Correlation Analyses

Pearson correlation coefficient (*r*) was used to measure the correlation between ARGs and environmental factors, including antibiotic residues and water quality parameters. *p* value was used to determine the significance of the correlation from a statistical point of view. Statistical analyses were conducted using SPSS Statistics.

RESEARCH RESULTS AND DISCUSSIONS

The physical parameters of the water in each lagoon are listed in Table 1. Conductivity, an indicator of the amount of total dissolved salts, decreased in the beef lagoon series, but not in the swine lagoon series. Besides, beef lagoons had much higher conductivity than swine lagoons. ORP was low in B4 and decreased from S1 to S3. The beef lagoons had higher levels of TS and VS than did the swine lagoons, while the TSS levels in the two lagoons systems were similar, suggesting the difference in TS and VS were mainly due to the dissolved solids.

Table 1. Physical parameters of the water in each livestock lagoon. “B” and “S” stand for beef and swine lagoons, respectively. The first number indicates the order of the lagoon in the corresponding multi-stage lagoon system, while the second number represents the depth (in feet) of sampling point underneath the lagoon water surface.

	Conductivity (μs/cm)	ORP (mV)	TS (g/L)	VS (g/L)	TSS (g/L)
B1-1	6612	85.2	5.47	1.40	0.54
B2-1	4760	107.8	3.63	1.12	0.19
B3-1	4192	123.6	3.45	1.13	0.25
B4-1	4185	84.1	3.72	1.18	0.45
S1-1	1718	175.1	0.99	0.50	0.32
S2-1	876	157.8	0.57	0.18	0.04
S3-1	1728	153.9	0.78	0.33	0.19

The chemical parameters of the water in each lagoon are listed in Table 2. The concentrations of chloride, sulfate, Zn, and Cu in the beef lagoons were generally higher than those in the swine lagoons. In beef lagoons the concentrations of ammonia, sulfate, Zn, and Cu were lower in the last lagoon compared to those in the prior lagoons. In swine lagoons the concentrations of contaminants were often similar between S1 and S3, and were the lowest in S2. Both the beef lagoons and the swine lagoon were able to lower the concentrations of some contaminants, while failed for other contaminants. For example, COD hardly dropped from B1 to B4. High levels of nutrients could promote bacterial growth and consequently increased the risk of the propagation and spread of ARGs.

Table 2. Chemical parameters of the water in each livestock lagoon.

	COD (mg/L)	NH_4^+-N (mg/L)	NO_3^--N (mg/L)	NO_2-N (mg/L)	OP (mg/L)	Sulfate (mg/L)	TP (mg/L)	Zn (μg/L)	Cu (μg/L)
B1-1	1400	23.9	9.57	<0.10	7.64	377.6	21.8	20.4	64.9
B2-1	1200	43.1	5.06	0.46	7.00	134.8	19.1	16.2	28.8
B3-1	1300	13.5	<0.10	<0.10	7.50	54.6	24.3	8.8	13.4
B4-1	1200	0.1	0.15	3.04	9.30	28.9	28.6	5.5	17.0
S1-1	300	104.0	<0.10	<0.10	5.86	40.9	10.4	2.8	1.3
S2-1	100	2.1	1.44	0.34	3.38	20.3	10.2	2.6	1.9
S3-1	400	97.1	<0.10	<0.10	5.44	41.8	15.2	1.7	9.2

At least one sulfonamide compound was detected in four of the five water samples collected from the beef lagoons and four of the six water samples from the swine lagoons. In addition, at least one tetracycline compound was detected in two of the five water samples of the beef lagoons and three of the six water samples of the swine lagoons. The total concentration of all sulfonamide compound detected in water samples were lower than 2 ng/mL, and the total concentration of all tetracycline compounds detected were lower than 8 ng/mL (Figure 2, A and B). Tetracyclines and sulfonamides were detected in all sediment samples (Figure 2, C and D). In particular, the level of total tetracycline in sediment was at a very high level (50.6-8907.7 ng/g).

Due to their higher adsorption to particulates, it is not surprising that the tetracycline compounds were accumulated in the sediment but not in the water. Both tetracyclines and sulfonamides are often resistant to chemical and biological degradation, causing them persistent in the environment. In this study, sulfonamides were present in both water and sediment at low abundance. This might be due to the decreasing use sulfonamides in the livestock facility. Overall, the beef lagoons had higher levels of sulfonamides than did the swine lagoons. In comparison, the swine lagoons had higher levels of tetracyclines than did the beef lagoons. The differences may result from the different antibiotic uses in the beef cattle and swine facilities.

It was noticed that the types of antibiotics in water did not always match those in sediment, and usually water samples contained more kinds of antibiotics than their corresponding sediment counterparts. For example, STZ, SMZ, SCZ, SMXZ, and OTC were not detected in sediment, but they were detected in some of the water samples. On the other hand, SMRZ did not appear in the water of B4 and S1 but was detected in the sediment of these two lagoons. Also, it was noticed that the total concentrations of tetracycline compounds and sulfonamide compounds in the water samples were much lower than the lowest minimum inhibitory concentrations (MIC) reported. For example, the MIC for sulfamethoxazole is 250μg/L, and the MIC for tetracycline 60μg/L. Given the low antibiotic concentrations in the water samples, the bacteria in lagoon water were exposed to sub-inhibitory concentrations of antibiotics. Exposure to antibiotic with sub-inhibitory concentrations could result in the development and growth of antibiotic resistance bacteria (Witte 1998; Anderson *et al.* 2003).

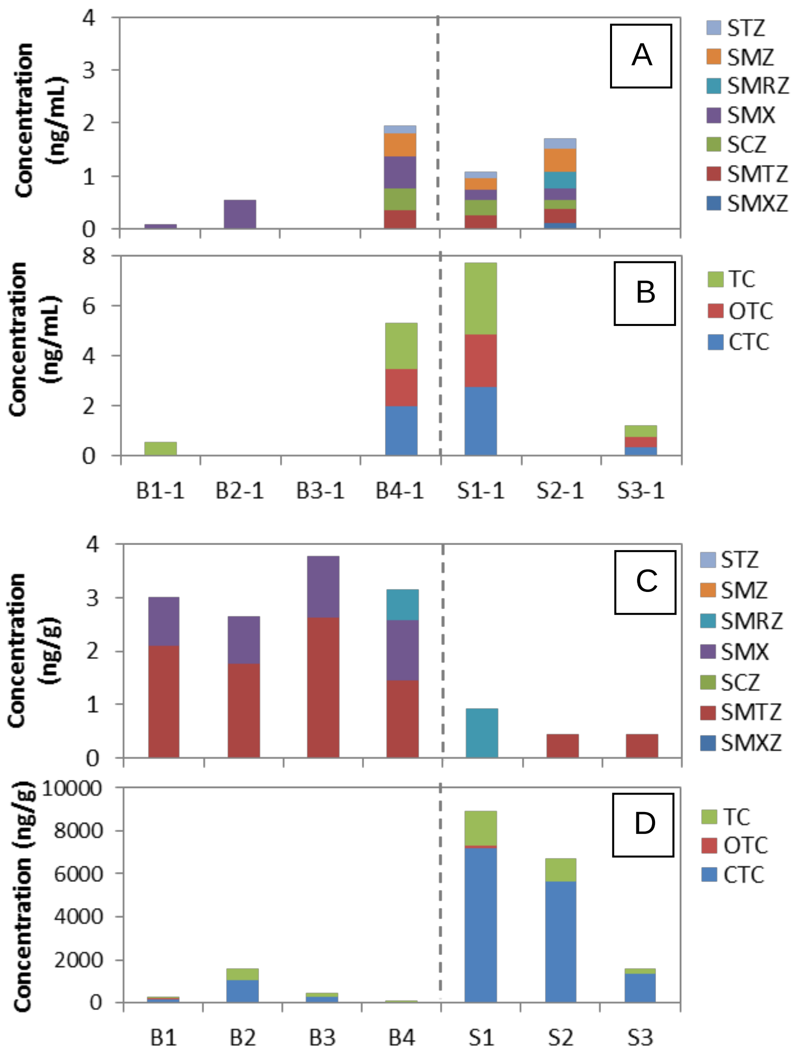

Figure 2. Concentrations of sulfonamide compounds and tetracycline compounds in lagoon water samples (A and B) and in lagoon sediment samples (C and D).

The ARG results of this study are reported in normalized values, which were calculated by dividing the copy number of an ARG in a sample to the copy number of the16S rRNA gene. Among the ARGs studied, *sul(II)* and *tet(Q)* had the highest relative abundance, while *tet(D)* had the lowest relative abundance in the two lagoon systems. The ARGs *sul(I)*, *tet(O),* and *tet(Q)* in the swine lagoons were much higher than those in the beef lagoons. The ARGs *sul(I), sul(II),* and *tet(X)* were significantly higher in water than in sediment (p<0.05). The last lagoon of each multi-stage lagoon system (i.e. B4 and S3) usually had lower ARG levels than the first lagoon of each system, although often no clear trends were observed when the middle lagoons are also included (Figure 3).

Efforts were made to search for correlation between the relative abundance of ARGs and their corresponding antibiotics in water and in sediment. For water samples, no significant correlation were observed between ARGs and corresponding antibiotics (data not shown). For sediment samples, the ARG *tet(O)* appeared to be highly correlated with each of the three tetracycline compounds tested with Pearson correlation coefficients ranging from 0.948 to 0.985 (p<0.01, Table 3). The Pearson correlation coefficients for other correlation are either low or not statistically significant. The ARGs *sul(I)* and *sul(II)* had no statistically significant correlation with any individual sulfonamide compound or the total sulfonamide (p>0.05, data not show). Lack of strong correlations between ARGs and their corresponding antibiotics indicates that the presence of antibiotics may not play a determinant role in enriching ARGs.

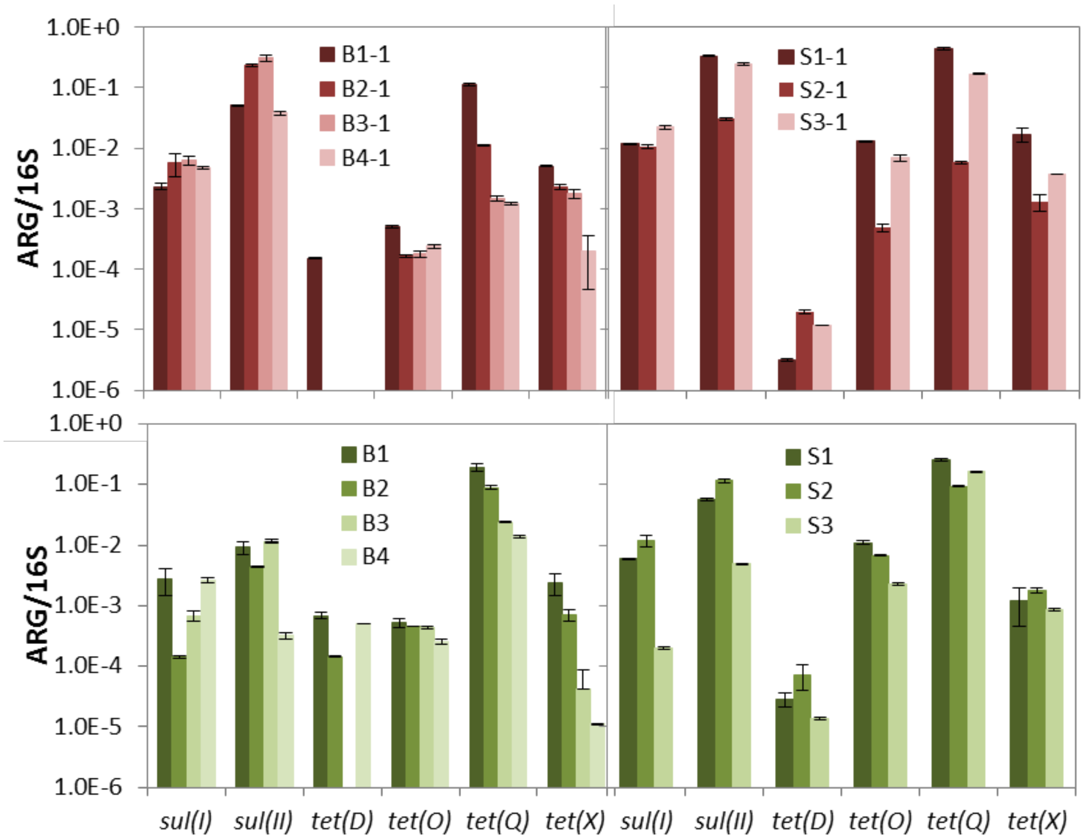

Figure 4. ARGs in surface water sample (upper) and sediment sample (bottom) of each lagoon

Table 3. Correlations between tetracycline resistance genes and tetracyclines in sediment samples.

	tet(D)	*tet(O)*	*tet(Q)*	*tet(X)*
CTC	-0.484	**0.985**	0.558	0.363
	0.272	*0.000*	*0.193*	*0.424*
OTC	-0.434	**0.971**	0.642	0.294
	0.330	*0.000*	*0.120*	*0.522*
TC	-0.501	**0.948**	0.553	0.296
	0.252	*0.001*	*0.198*	*0.519*
total tetracycline	-0.488	**0.983**	0.560	0.352
	0.266	*0.000*	*0.191*	*0.438*

In sediments, the ARGs *sul(I)* and *sul(II)* had strong positive correlation with each other (r=0.998, p<0.05), while in water the ARGs *tet(O)*, *tet(Q)*, and *tet(X)* had strong correlation with each other (r>0.7, p<0.05). Strong correlations among the same class of ARGs imply coexistence of these genes in bacterial cells.

In addition to antibiotics, other water quality parameters were also investigated for their potential correlation with ARGs. As shown in Table 4, ORP showed strong positive correlation with *sul(I), tet(O)* and, *tet(Q)*. Ammonia showed strong correlation with *tet(O)*, *tet(Q)* and *tet(X)*. TSS also showed positive correlation with *tet(O)* and *tet(Q).* Co-selection of metal resistance and antibiotic resistance are often observed (Baker-Austin *et al.* 2006; Wardwell *et al.* 2009). In this study, only Cu and *tet(D)* exhibited strong positive correlation.

Table 4 Correlations between ARGs and water quality parameters. Only those having significant correlation with at least one ARG are listed.

	sul(I)	*sul(II)*	*tet(D)*	*tet(O)*	*tet(Q)*	*tet(X)*
Conductivity	**-0.690**	-0.023	-0.170	-0.575	-0.512	-0.295
	0.019	*0.947*	*0.617*	*0.064*	*0.107*	*0.378*
ORP	**0.700**	0.284	0.081	**0.727**	**0.696**	0.562
	0.017	*0.397*	*0.812*	*0.011*	*0.017*	*0.072*
TSS	-0.018	-0.173	0.031	**0.735**	**0.658**	0.234
	0.959	*0.611*	*0.928*	*0.010*	*0.028*	*0.489*
Ammonia	0.651	0.561	-0.363	**0.810**	**0.807**	**0.655**
	0.030	*0.073*	*0.272*	*0.002*	*0.003*	*0.029*
Chloride	**-0.743**	-0.185	-0.049	**-0.635**	-0.564	-0.353
	0.009	*0.585*	*0.887*	*0.036*	*0.070*	*0.287*
Cu	-0.624	-0.343	**0.773**	-0.471	-0.261	-0.200
	0.099	*0.406*	*0.024*	*0.239*	*0.533*	*0.636*

CONCLUSIONS

The following conclusions have been drawn from this study.

1. The concentrations of sulfonamides were low in both water and sediment of the beef and swine lagoons tested (<2 ng/mL in water and <5 ng/g in sediment). The concentrations of tetracyclines were < 8 ng/mL in water, while were ranged between 50.6 and 8907.7 ng/g in lagoon sediment. Our results confirmed that tetracyclines have high affinity to particulate matters.
2. Among the ARGs, *sul(II)* and *tet(Q)* had the highest relative abundance, while *tet(D)* had the lowest relative abundance in the lagoons studied. The relative abundance of ARGs in the last lagoon of each lagoon system was often lower than that in the first lagoon of the series.
3. Correlation analysis showed that only *tet(O)* had a strong positive correlation with its corresponding antibiotics, CTC, OTC, and TC (r>0.94, p<0.05). Strong correlations between ARGs were observed, implying coexistence of the genes in bacterial cells.
4. Among tested water parameters, ORP, TSS, ammonia and Cu had strong positive correlation with at least one ARG. Other parameters such as COD, TP, OP, VS and Zn had no significant correlation with any ARG.

REFERENCES

Aminov, R., N. Garrigues-Jeanjean and R. Mackie (2001). Molecular ecology of tetracycline resistance: Development and validation of primers for detection of tetracycline resistance genes encoding ribosomal protection proteins. Applied and Environmental Microbiology: 22-32.

Anderson, A., J. Nelson, S. Rossiter and F. Angulo (2003). Public health consequences of use of antimicrobial agents in food animals in the United States. Microbial Drug Resistance-Mechanisms Epidemiology and Disease: 373-379.

Baker-Austin, C., M. Wright, R. Stepanauskas and J. McArthur (2006). Co-selection of antibiotic and metal resistance. Trends in Microbiology: 176-182.

Fan, W., T. Hamilton, S. Webster-Sesay, M. Nikolich and L. Lindler (2007). Multiplex real-time SYBR Green IPCR assay for detection of tetracycline efflux genes of Gram-negative bacteria. Molecular and Cellular Probes: 245-256.

Ghosh, S., S. Ramsden and T. LaPara (2009). The role of anaerobic digestion in controlling the release of tetracycline resistance genes and class 1 integrons from municipal wastewater treatment plants. Applied Microbiology and Biotechnology: 791-796.

Li, B. and P. Bishop (2002). Oxidation-reduction potential (ORP) regulation of nutrient removal in activated sludge wastewater treatment plants. Water Science and Technology: 35-38.

Pei, R. T., S. C. Kim, K. H. Carlson and A. Pruden (2006). Effect of River Landscape on the sediment concentrations of antibiotics and corresponding antibiotic resistance genes (ARG). Water Research **40**(12): 2427-2435.

Suzuki, M., L. Taylor and E. DeLong (2000). Quantitative analysis of small-subunit rRNA genes in mixed microbial populations via 5 '-nuclease assays. Applied and Environmental Microbiology: 4605-4614.

Wardwell, L., B. Jude, J. Moody, A. Olcerst, R. Gyure, R. Nelson and F. Fekete (2009). Co-Selection of Mercury and Antibiotic Resistance in Sphagnum Core Samples Dating Back 2000 Years. Geomicrobiology Journal: 351-360.

Witte, W. (1998). Medical consequences of antibiotic use in agriculture. Science: 996-997.

Wireless Underground Sensor Networks for Irrigation Management

Basic Information

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Publications

1. Silva, Agnelo and Mehmet C. Vuran, 2010, ``Development of a Testbed for Wireless Underground Sensor Networks," EURASIP Journal on Wireless Communications and Networking special issue on "Simulators and Experimental Testbeds Design and Development for Wireless Networks", vol. 2010, Article ID 620307, 14 pages.
2. Dong, Xin and Mehmet C. Vuran, 2010, ``Spatio-temporal Soil Moisture Measurement with Wireless Underground Sensor Networks," in Proc. IFIP Med-Hoc-Net '10, Juan-les-pins, France, June.
3. Silva, Agnelo and Mehmet C. Vuran, 2010, ``(CPS)^2: Integration of Center Pivot Systems with Wireless Underground Sensor Networks for Autonomous Precision Agriculture," in Proc. ACM/IEEE Int. Conf. on Cyber-physical Systems (ICCPS '10), Stockholm, Sweden, April.
4. Silva, Agnelo and Mehmet C. Vuran, 2010, ``Communication with Aboveground Devices in Wireless Underground Sensor Networks: An Empirical Study," in Proc. IEEE Int. Conf. on Communication (ICC '10), Cape Town, South Africa, May.
5. Dong, Xin and Mehmet C. Vuran, 2011, "(CPS)^2: Autonomous Precision Agriculture through Integration of Wireless Underground Sensor Networks with Center Pivot Systems," submitted for journal publication.
6. X. Dong and M. C. Vuran, "A Channel Model for Wireless Underground Sensor Networks Using Lateral Waves," in preparation, 2011.

Wireless Underground Sensor Networks for Irrigation Management
Annual Report 2010-2011
Project Number: 2010NE209B

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Contents

1 Water Problem

According to a recent United Nations' report [11], nearly 70% of all water usage is related to agriculture irrigation. Moreover, the world's population is expected to double by 2050. Considering the ever growing need for food and the diminishing water resources due to climate changes, developing efficient irrigation management techniques is essential. Irrigation management is an *underground* application that has been developed for more than 20 years [9]. The existing techniques, however, lack the *real-time information retrieval capabilities* that limit both their applicability and effectiveness. To this end, a wireless underground sensor network (WUSN), which consist of wireless sensors buried underground, has the potential to help reduce water application to the agricultural fields through real-time measurement of soil moisture status to make better informed irrigation application (timing) decisions without obstructing with the field operations. As a result, *the cost for maintaining a crop field can be significantly reduced* through *autonomously operating underground sensors that control irrigation application*. The project topics are inline with the #1 and #7 of *the top* 10 *water challenges for Nebraska*.

2 Research Objectives

The **objectives** of the proposed project are threefold: (1) *Design and implementation of a cross-layer communication module* for environment-aware underground networking in agricultural fields, (2) *Implementation of an irrigation management testbed*, where WUSNs will be integrated with a center pivot system to realize autonomous irrigation management through real-time soil moisture information from underground sensor nodes, and (3) *Development of hands-on educational tools and provide experiences in WUSNs.*

3 Executive Summary

3.1 Resarch and Education Activities

In this project, the development of wireless *underground* sensor networks (WUSNs), which carries information *through soil*, is investigated. Moreover, the application of underground networking techniques in agricultural applications are considered. The results have potential impacts in decreasing the costs of irrigation, which constitutes 70% of all water usage in the world. In the following, the research and education activities within this project are summarized.

The characteristics of communication links between underground sensor nodes and aboveground management nodes are investigated through extensive testbed experiments. The results of this investigation reveal that soil moisture significantly impacts communication performance. Thus, an antenna scheme is developed to mitigated these impacts. The results of these studies are exploited to develop an irrigation testbed in a 40-acre corn field, where a WUSN is integrated with a center-pivot irrigation system.

3.1.1 Cross-layer Communication Platform

A WUSN requires devices on the ground for data retrieval, management, and relay functionalities. Hence, communication between underground sensors and an irrigation management node should be reliably provided. These links consist of underground and aboveground portions and have not been characterized before. To characterize underground-to-aboveground and aboveground-to-underground communication links, extensive testbed experiments have been conducted with commodity sensor motes in an agricultural field. An underground antenna scheme is implemented to combat the adverse effects of soil moisture and improve antenna matching. Using this scheme, experiments have been conducted under different antenna configurations, burial depths, and soil moisture levels. The results of this investigation are reported in [16].

3.1.2 Irrigation Management Testbed

The experiences gained in characterizing the underground-aboveground communication links and the soil moisture have been exploited to develop an irrigation management testbed. The testbed provides a proof-of-concept for the feasibility of WUSN in agriculture applications. A WUSN is integrated with a center-pivot irrigation system, which is native to Nebraska and has been used throughout the Nation. To this end, 8 underground sensors are deployed on a 40-acre corn field and an aboveground mote is attached to a mobile center pivot system. Through extensive field experiments, the effects of the inter-node distance, vegetation canopy, and soil moisture on communication performance are investigated. Real-time data delivery performance of the system is evaluated. Based on empirical results, channel models for both the UG2AG link and the AG2UG link are evaluated. The results are reported in [6, 15].

3.1.3 Education and Training Activities

As an integral part of the project, the developed communication and networking concepts are integrated into education activities. More specifically, underground sensor networking concepts are included in a textbook on wireless sensor networks [4]. Moreover, through course projects in Sensor Networks and Embedded Systems classes, the PI has involved undergraduate and graduate students in solving research problems in the areas of wireless underground sensor networks, multimedia sensor networks, and aerial sensor networks. The course activities have been conducted using an interactive sensor network. To this end, a software/hardware backbone is implemented that provides remote programming, out-of-band monitoring, power management, and virtual sensing. As a part of this effort, an undergraduate student is supported through a UNL Undergraduate Creative Activities and Research Experiences (UCARE) grant in Summer 2010 and another student has been awarded the UNL UCARE grant for Summer 2011. In collaboration with the 4-H program, a summer camp module is designed to teach wireless underground networks to “little farmers”.

3.2 Major Findings

3.2.1 Cross-layer Communication Platform

The empirical evaluations of underground communication have revealed several important characteristics of WUSNs. Initial field tests reveal that traditional antennas perform poorly in underground settings [14]. This is mainly due the antenna mismatch, when an RF signal of a certain carrier frequency enters the soil. Due the difference in air and soil impedance, an underground antenna should be designed to match a wavelength that is lower than the wavelength of the original signal in air. Moreover, this difference depends on the soil moisture, which is variable. An underground antenna scheme is implemented to combat the adverse effects of the change in wavelength in soil. The new antenna scheme is shown to increase the communication range by up to 300% compared to the original antennas [16]. Moreover, the developed antenna scheme is evaluated under different environmental factors. It is shown that a 21% increase in soil moisture decreases the communication range by more than 70%. These results have significant impacts on the development of communication and networking protocols for WUSNs. The results of this investigation are reported in [16].

3.2.2 Irrigation Management Testbed

The results of the channel investigation have been exploited to develop a large-scale WUSN testbed in a 40-acre corn field. Successful communication with a center-pivot system and an underground sensor network has been demonstrated in real-life agriculture fields [6, 17, 15]. Several experiments have been performed during different times of the year with different soil moisture and vegetation levels and different orientation of the underground antenna. During an 8.37 hr run of a complete circle of the system, 29.7 min and 1.33 hrs communication windows are recorded for vertical and horizontal antenna orientations, respectively. Based on the empirical measurements, a semi-empirical channel model is developed for communication between underground and aboveground nodes. Moreover, it is found that, the canopy results in a 3 dB increase in attenuation and an increase in soil moisture from 16.6% to 22.7% results in yet another 3 dB increase in attenuation. The results are reported in [6, 17, 15].

3.3 Education and Training

3.3.1 Graduate Education

The project has partly supported 2 M.S. and 2 Ph.D. students towards their dissertations. The PI and the graduate students have been involved in developing an underground testbed in real-life agricultural settings. Working in an agriculture field within the constrains of environment and crop schedules have provided significant experience in terms of scheduling research activities and tailoring communication and networking research under these constraints.

3.3.2 Undergraduate Education

During this investigation period, an undergraduate student, Mr. Cheney So, has been recruited and supported through a UNL UCARE award. He has engaged in developing an interactive testbed for wireless sensor network research. Moreover, an undergraduate student, Mr. Tanner Dozark has been awarded a UNL UCARE award for the development of education modules for summer camps with the 4-H program based on the results gathered in this project.

The PI has been actively involved in integrating concepts in underground communication and networking within undergraduate and graduate-level courses. The findings have been also included in a textbook on wireless sensor networks [4].

3.4 Outreach Activities

The PI has been collaborating with the 4-H program, which provides summer and yearly camps throughout the nation an is supported but another NSF project. The findings of this project are being integrated into summer camp modules for K-12 students to engage and participate in underground communication research. The camp module includes a mine sweeper game, where the students will use Lego NXT robots to locate underground sensor nodes using wireless communication techniques. The module will be first implemented and tested with the 4-H trainers and an initial deployment will be performed in July 2011.

The significance of the project include facilitating more efficient irrigation management technologies through real-time soil information provided by WUSNs. The PI has disseminated the results of the research as a panelist in the UNL Water for Food conference, National Public Radio (NPR) news, MIT Technology Review journal, and Nebraska Farmer Magazine. Through these outreach activities, technological improvements in and the impacts of underground communication on agriculture are disseminated.

3.5 Contributions

The results of this project have been published in and submitted to top conference and journals in communication and networking [5, 6, 15, 16, 17]. The study of underground communication and networking through empirical evaluations has not been performed before. The findings of this project provide important insight into the feasibility of integration of underground communication and networking with center pivot irrigation systems and their impacts on agriculture. The education components of the project provide significant awareness of wireless networking in general, and underground communication in particular, in agriculture applications. Through outreach for K-12 students, these concepts are introduced early to stimulate interest in computer science and engineering disciplines.

The PI has demonstrated the first integration of underground sensor networks with center-pivot irrigation systems. This study has highlighted the feasibility of using wireless underground communication techniques to improve precision agriculture techniques with low-cost solutions. The impacts of this work are reported during

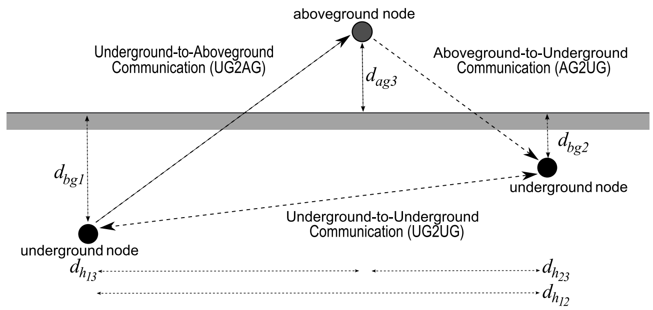


Figure 1: Types of communication links in WUSNs: UG2UG, UG2AG, and AG2UG.

the UNL Water for Food conference, National Public Radio (NPR) news, MIT Technology Review journal, and Nebraska Farmer Magazine.

The remainder of this report is organized as follows: In Section 4, the empirical evaluations for communication between underground and aboveground sensor nodes are presented. The irrigation testbed development and experiment results are discussed in Section 5. Educational activities including course projects, interactive tool implementation, and summer camp development, are presented in Section 6. Finally, the publications resulted from this research are listed in Section 8.

4 Cross-layer Communication Platform

4.1 Motivation

Although its deployment is mainly based on underground sensor nodes, a WUSN still requires aboveground devices for data retrieval, management, and relay functionalities. Accordingly, three different communication links exist in WUSNs based on the locations of the transmitter and the receiver as shown in Fig.1:

- *Underground-to-underground (UG2UG) Link:* Both the sender and the receiver are buried underground and communicate through soil [14, 22]. This type of communication can be employed for multi-hop information delivery.
- *Underground-to-aboveground (UG2AG) Link:* The sender is buried and the receiver is above the ground. Monitoring data is transferred to aboveground relays or sinks through these links.
- *Aboveground-to-underground (AG2UG) Link:* Aboveground sender node sends messages to underground nodes. This link is used for management information delivery to the underground sensors.

UG2AG and AG2UG links are required for several functionalities of WUSNs, such as network management and data retrieval. Since both links include underground propagation, the soil properties, such as soil moisture, directly impact the communication success. Moreover, the soil-air interface plays an important role in communication. Transmitted rays are reflected and attenuated at this interface, which significantly influences the channel quality. This influence also varies depending on the direction of the transmission (UG2AG or AG2UG). Furthermore, the wavelength of a radio frequency (RF) signal is significantly reduced when propagating through soil [14, 18, 21]. The relations between the wavelength change and the design aspects of an underground antenna should be clearly identified.

In the following, we present the results of empirical evaluations for UG2AG and AG2UG communication links. More specifically, testbed experiments have been conducted with commodity sensor motes in a real-life agricultural field. To combat the adverse effects of underground communication, an underground antenna scheme is developed and tested. We particularly consider agricultural applications of WUSNs, which usually require burial depths greater than 30cm due to plowing and similar mechanical activities at the soil [14]. Accordingly, the majority of the experiments consider a 35cm burial depth.

4.2 Experimental Methodology

The underground experiments are carried out with 433MHz Mica2 [1] sensor nodes in South Central Agricultural Laboratory (SCAL) of the University of Nebraska-Lincoln, located at Clay Center, NE. The analysis of the soil texture, the particle density, and the bulk density of the site are shown in Table 1 [24]. To observe the effects of soil moisture, two different volumetric water content (VWC) values are considered, i.e., *dry* soil (VWC_{dry} = 9.5%) and *wet* soil (VWC_{wet} = 37.3%).

Table 1: Soil parameters used in the experiments.

Depth	Texture	Sand	Silt	Clay
0-20cm	Silt Loam	17	55	28
20-60cm	Silt Clay Loam	16	46	38

Particle density	Bulk density
2.66g/cm^3	1.3g/cm^3

The terminology used in this work is shown in Fig.1, where d_{bg} is the burial depth, d_{ag} is the height of the aboveground node, and d_h is the horizontal distance between the sender and the receiver nodes. For the experiments, a Java/TinyOS 1.1x application, called S-GriT (Small Grid Testbed for WSN Experiments) [14, 17], is developed to enable carrying out several experiments without reprogramming the sensor nodes. For the experiments, the packet error rate (PER) and the received signal strength (RSS) level for the received packets are collected. The maximum transmit power level of the Mica2 (+10dBm) is used. The size of each packet is 37 bytes and a 100ms delay between each packet transmission is configured. Each experiment is based on a set of 3 tests with 350 messages each, which result in a total of 1050 packets.

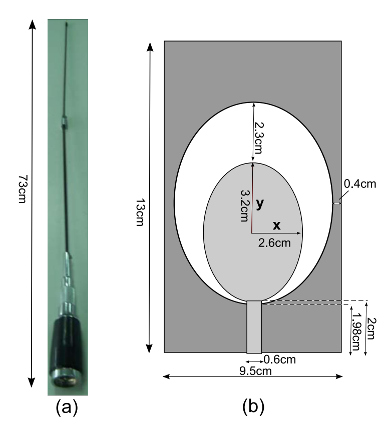


Figure 2: (a) Aboveground antenna. (b) Customized underground antenna.

4.3 Antenna Design

To combat the adverse effects of underground communication, we design a specific antenna scheme and compare it with existing antennas. In the experiments, two different antenna schemes are used:

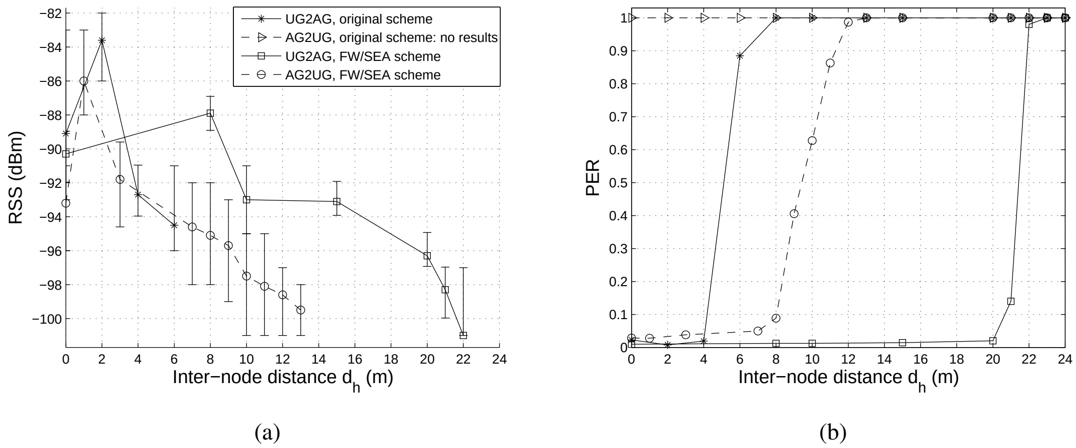


Figure 3: (a) RSS and (b) PER for the different antenna schemes: original antennas and FW/SEA.

FW/SEA: A customized ultra wideband single ended elliptical antenna (SEA) [13] is used for the underground node (Fig.2(b)) and a commercial magnetic 433MHz, full-wave (FW), 3dBi-gain antenna is used for the aboveground node (Fig.2(a)).

Original: refers to the use of the original antenna of the 433MHz Mica2 motes, which is a standard one-quarter wavelength monopole antenna. The antennas are vertically oriented [14, 17].

The reason for using a custom antenna scheme is explained as follows: The high relative permittivity of the soil causes a significant reduction of the wavelength of the EM waves when traveling from air to soil. Moreover, the soil moisture is an important factor in this reduction. These facts have a significant impact on the design of an underground antenna. An *underground* antenna must be designed to match a nominal frequency *higher* than the original frequency used by an aboveground antenna. More specifically, the wavelength of the underground signal, λ, when it propagates through the soil is given by [18]:

$$\lambda = \frac{2\pi}{\beta}, \quad \beta = \frac{2\pi c}{\lambda_0}\sqrt{\frac{\mu_r \mu_0 \epsilon' \epsilon_0}{2}\left[\sqrt{1+\left(\frac{\epsilon''}{\epsilon'}\right)^2}+1\right]}\,, \tag{1}$$

with respect to the wavelength in free space, λ_0, where β is the phase shifting constant in $radian/m$, μ_r is the relative permeability of the soil ($\mu_r = 1$ for non-magnetic soil), $\mu_0 = 4\pi * 10^{-7} N/A^2$ is the magnetic constant, and ϵ' and ϵ'' are the real and imaginary parts of the relative permittivity of the soil.

The dielectric properties of the soil, represented by the parameters ϵ' and ϵ'' are significantly affected by the changes in soil properties [12]. Based on the soil parameters shown in Table 1, the operating frequency of 433MHz, and the minimum and maximum measured VWC values observed in the experiment site, the numerical results show that the antenna for this environment should have a dynamic wavelength ranging from 30-69cm, which correspond to antennas that match to the 1-1.8GHz range in free space. Accordingly, an ultra wideband (UWB) antenna is implemented based on a Single Ended Elliptical Antenna (SEA) design [13]. The physical measurements of the implemented antenna are shown in Fig.2(b).

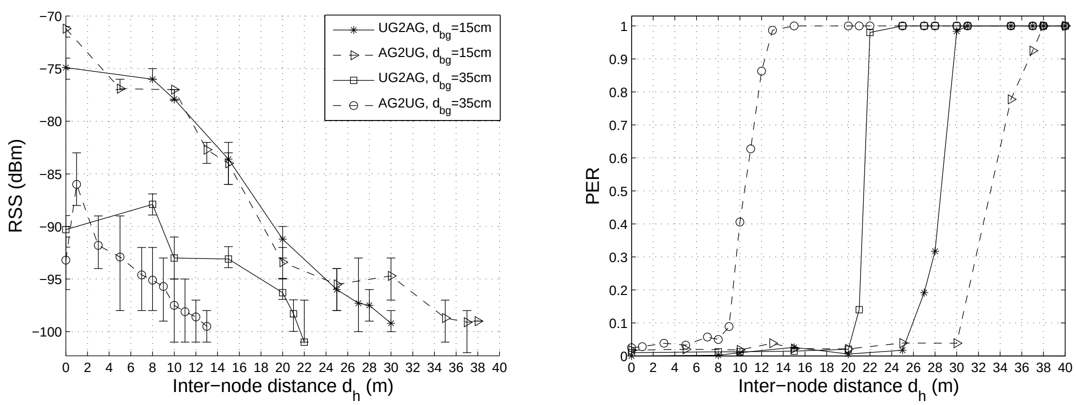
4.4 Experiment Results

In this section, an empirical analysis of the impacts of antenna design, burial depth, and soil moisture on UG2AG and AG2UG communication performance are presented.

4.4.1 Effects of the Antenna Design

Experiments are performed with the original and the FW/SEA antenna schemes, with fixed depth (d_{bg}=35cm) and height (d_{ag}=2.5m) and the horizontal inter-node distance, d_h, is varied from 0 to 25m. In Figs.3(a) and 3(b), the RSS and PER values are shown, respectively, as a function of the horizontal inter-node distance, d_h.

As shown in Fig.3(a), an increase in the horizontal inter-node distance, d_h, decreases the signal strength, as expected. However, in the region close to the buried sensor (d_h<1m), a monotonic decrease is not observed. This is related to the near-field effects of the omnidirectional antennas, where *nulls* occur at locations very close to the antenna axis. As shown in 3(b), the FW/SEA scheme combats the adverse effects of the change in wavelength in soil. More specifically, for UG2AG links, communication range is increased by 250% from 6m to 21m. Furthermore, while AG2UG communication is not possible with traditional antennas, the developed FW/SEA scheme provides communication distance of 8m.

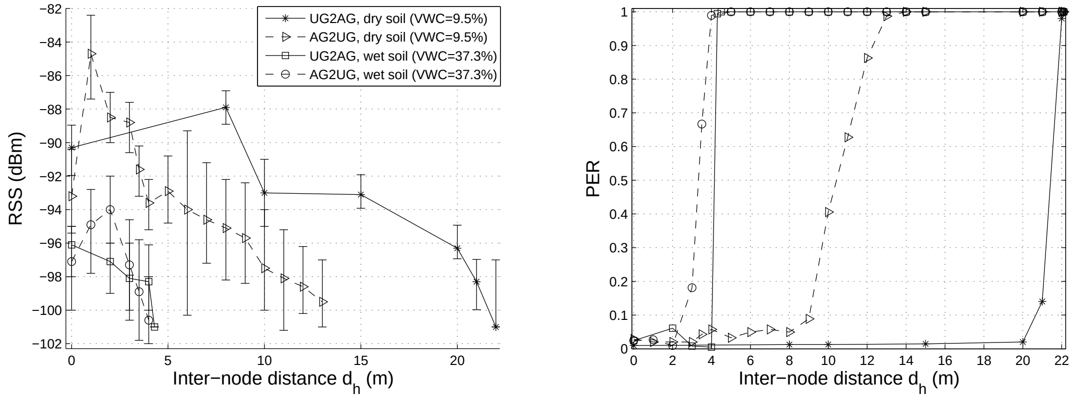


(a) (b)

Figure 4: (a) RSS and (b) PER for different burial depths: 15cm and 35cm and with the FW/SEA scheme.

4.4.2 Effects of Burial Depth

The effects of the burial depth on communication is shown in Figs. 4(a) and 4(b), where the FW/SEA antenna scheme is used for burial depths, d_{bg}, of 15 and 35cm, and the horizontal inter-node distance, d_h, is varied from 0 to 40m. For both UG2AG and AG2UG communication, the higher burial depth (d_{bg}=35cm) is associated with an increase in attenuation. For instance, at d_{bg}=15cm and d_h=8m, the signal strength for both UG2AG and AG2UG is -76dBm. However, for a deeper deployment (d_{bg}=35cm) and the same inter-node distance, the received signal strengths are 16% (-88dBm) and 25% (-95dBm) lower for UG2AG and AG2UG links, respectively. It can also be observed in Fig.4(a) that the variance of RSS is slightly larger for the AG2UG communication at d_{bg}=35cm. This result suggests that the multi-path effects are particularly stronger for the



(a) (b)

Figure 5: Effects of the soil moisture on the UG2AG and AG2UG communication.

combination of AG2UG and high burial depths.

Shallower burial depths can significantly enhance both UG2AG and AG2UG communication distances. When the burial depth changes from 35cm to 15cm, the communication range is extended by approximately 40% and 300% for UG2AG and AG2UG links, respectively, as shown in Fig.4(b). The significant increase in the communication range of AG2UG link reveals that the AG2UG link has a higher sensitivity to the soil properties and refraction.

4.4.3 Effects of Soil Moisture

The effects of soil moisture on the signal strength and PER are investigated by experiments, where the depth (d_{bg}=35cm) and the height (d_{ag}=2.5m) are fixed and the horizontal inter-node distance, d_h, is varied from 0 to 22m for two soil moisture levels, VWC_{dry} (9.5%) and VWC_{wet} (37.3%). The latter VWC value represents the saturation point of the soil in our testbed.

In Figs. 5(a) and 5(b), the RSS and PER values are shown, respectively, as a function of the horizontal inter-node distance. The increase in soil moisture from 9.5% to 37.3% causes an additional attenuation of 8dB, on the average, and the communication range decreases by approximately 80% and 70% for UG2AG and AG2UG links, respectively. An increase in the soil moisture has two main effects on the wireless underground communication. First, the wavelength of the signal is decreased, which causes indirect loss due to the antenna mismatch, as explained in Section 4.2. The FW/SEA scheme reduces this first effect. Second, an increase in soil moisture significantly increases the soil attenuation [12, 10, 14, 22]. This result shows that soil moisture has a significant influence on the quality of UG2AG and AG2UG communication. Therefore, the design of the WUSN protocols should carefully adapt to the variation of the soil moisture.

An overview of the experiment results are shown in Table 2. In this table, the normalized transitional region width, Γ, is given by $\Gamma = (d_e^{tr} - d_b^{tr})/d_b^{tr}$, where d_b^{tr} and d_e^{tr} are the beginning and end of the transitional region, respectively [23]. The link presents PER$>10\%$ for inter-node distances higher than d_b^{tr}. No communication is observed for distances higher than d_e^{tr}.

Table 2: Overview of Results

Comm. Type	Antenna Scheme	Soil Moisture	Burial Depth	Maximum Range (d_b^{tr})	Transitional Region Coefficient (Γ)	Average Variance
$UG2AG$	original	Dry	15cm	11m	0.18	2.2
	FW/SEA	Dry	15cm	30m	0.16	3.0
	original	Dry	35cm	6m	0.33	5.2
	FW/SEA	Dry	35cm	22m	0.04	2.8
	FW/SEA	Wet	35cm	4.3m	0.06	3.5
$AG2UG$	FW/SEA	Dry	15cm	38m	0.21	2.4
	original	Dry	35cm	no comm.	–	–
	FW/SEA	Dry	35cm	13m	0.30	5.5
	original	Wet	35cm	no comm.	–	–
	FW/SEA	Wet	35cm	4m	0.25	5.0

5 Irrigation Management Testbed

5.1 Motivation

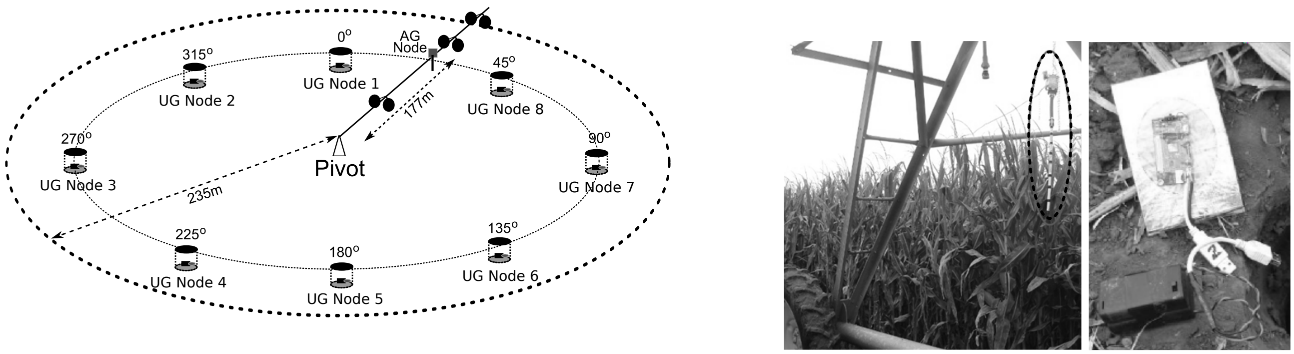
With the growth of the world population, the corresponding growth of the demand for food pushes agriculture into a new generation of practice called precision agriculture (PA). PA techniques focus on the existence of in-field variability of natural components, including topology, leaching, runoff, drainage, water content, nutrients, and soil components [7, 8]. The goal is to utilize new technologies, such as GPS, satellites, aerial remote sensing and sensors to assess the variations in a field more accurately. The evaluation results can then be used to schedule precise farming practices, including sowing, irrigating, fertilizing, and pest control. We aim to utilize WUSNs to provide an additional source of information for PA techniques. To this end, as a proof-of-concept, an irrigation testbed has been developed in UNL South Central Agriculture Lab (SCAL) in Clay Center, NE and in the following, we present the experiments with this testbed [6, 15].

5.2 Experiment Setup

Experiments are carried out with 433MHz Mica2 [1] sensor nodes in the South Central Agricultural Laboratory (SCAL). The analysis of the soil texture, particle density, and bulk density of the site where the center pivot is located, is shown in Table 1 according to laboratory analysis [24].

As shown in Fig. 6(a), the experiment involves one aboveground node (AG node) installed on the arm of a center pivot irrigation system, which is located on a corn field. The height of the AG node relative to the soil is 2.5m. The UG nodes are buried in the corn field in a circle. The center pivot is moved in both clock-wise and counter clock-wise directions and the communication between AG and UG nodes is established when the CP is within the communication range. A burial depth of 35 cm is used in the experiments. The FW/SEA antenna scheme explained in Section 4.3 is used for the experiments. The underground antennas are placed in two orientations: (1) vertically, where its minor ellipsis points to the direction of the center pivot (before its passage) and (2) horizontally.

For the experiments, a software application is developed to carry out several experiments without reprogramming the sensor nodes and without the use of cables connecting the sender-receiver pair of nodes. A transmit power level of +10dBm is used for all experiments. In each transaction, 100 packets are sent from the AG node to the UG node and from the UG node to the AG node, independently. The size of the test packet is 37



(a) (b) (c)

Figure 6: (a) Testbed topology for the experiments: An aboveground (AG) node is installed on the center pivot and 8 underground (UG) nodes are buried along its path, (b) final installation of the AG node on the center pivot (2.5m-height) and (c) 433MHz Mica2 mote with the SEA antenna near a 50cm deep hole.

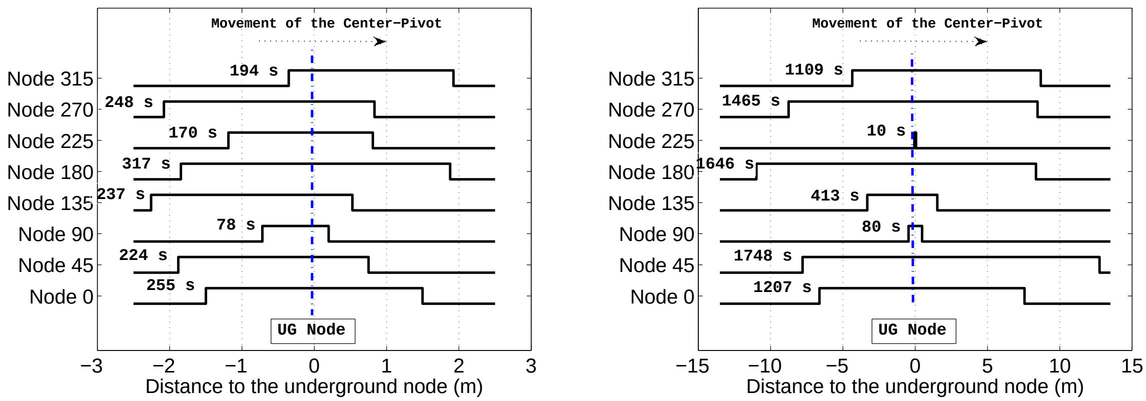
bytes and the interval between two packets is 100 ms. After an experiment, the experiment data is read out of the flash memory of each node. The timestamp of the packets is used to calculate the location of the AG node during the CPs its travel, given its speed. Four different experiments are realized with different conditions of soil moisture and vegetation canopy, as listed below:

- ***Experiment A***: The UG node is located at the position 0^o and the corn crop had been harvested. Hence, the effects of the vegetation canopy can be neglected. The volumetric water content (VWC) [7] is found to be 16.6%.
- ***Experiment B***: The experiment is realized at an area of the crop field where no vegetation canopy is present. Therefore, the canopy effect can be neglected. The the volumetric water content (VWC) is found to be 22.7%.
- ***Experiment C***: In a similar scenario as the Experiment B, but this experiment is performed in the field at a time when the corn crops reach its maximum height, 2.85m. Therefore, the wireless communication is performed subject to the effects of the canopy.
- ***Experiment D***: As Experiment C, it is realized in the field with the impact of the corn crops. However, the SEA antenna on the UG node is placed horizontally to achieve better transmission ranges.

Experiments A and B are performed with stationary nodes and experiments C and D are performed with the center pivot setup as shown in Fig. 6(a). The travel speed of center pivot is set to its maximum (43^o per hour) to analyze the worst-case scenario. At the circumference where the UG nodes are buried, this speed corresponds to 0.704 m/min.

5.3 Experiment Results

In this section, the effects of the inter-node distance between the AG and UG nodes on the UG2AG and AG2UG communication performance are discussed. Channel models for both the UG2AG link and the AG2UG link are



(a) Vertical UG antenna (b) Horizontal UG antenna

Figure 7: Communication windows between the AG node, installed on the center pivot, and the UG nodes.

evaluated using the empirical data. In addition, the effects of the vegetation canopy and soil moisture on communication are discussed.

5.3.1 Communication Range

The communication window of each node is shown in detail in Fig. 7, where the communication range is shown for each UG node in terms of horizontal distance and the time covered by the AG node while in motion. A negative distance represents the cases where AG node is approaching the UG node, whereas a positive value represents the cases where the AG node is moveing away from the UG node. The results for the vertical UG antenna (Experiment C) and the horizontal UG antenna (Experiment D) placements are shown in Fig. 7(a) and Fig. 7(b), respectively.

The results with horizontal placement (Fig. 7(b)) are significantly better than those with vertical placement (Fig. 7(a)). With vertical placement, most of the propagation area of the antenna resides within soil, whereas with horizontal placement, the node can receive information from air better.

The total traveling time of one circle of the system is 8.37 hours and the total communication time of all the nodes is 29.7min (vertical) and 1.33hrs (horizontal), or 6% (vertical) and 16% (horizontal) of the total traveling time. Also observed in the figure is the variation of the communication window among different nodes. As shown in Fig. 7(b), for the horizontal UG antenna placement, the longest communication time is 29 minutes or 20.6m (node 45^o) while the shortest time is only 10 seconds or 0.11m (node 225^o). With horizontal placement, the average communication distance is 8.75 m, with standard deviation $\sigma_{CCW} = 5.73$.

5.3.2 Channel Model for Soil-Air Communication

In Fig. 7, an asymmetry in the communication ranges is observed between the case when the AG node is approaching the UG node and when it is departing the UG node. To investigate the factors that result in this asymmetry, we also performed experiments, where the CP is moved in the opposite direction. The resulting RSS measurements are shown in Fig. 8 for 3 selected nodes. The relatively similar communication distances in both the clock-wise (CW) and counter clock-wise (CCW) directions reveal that the communication quality

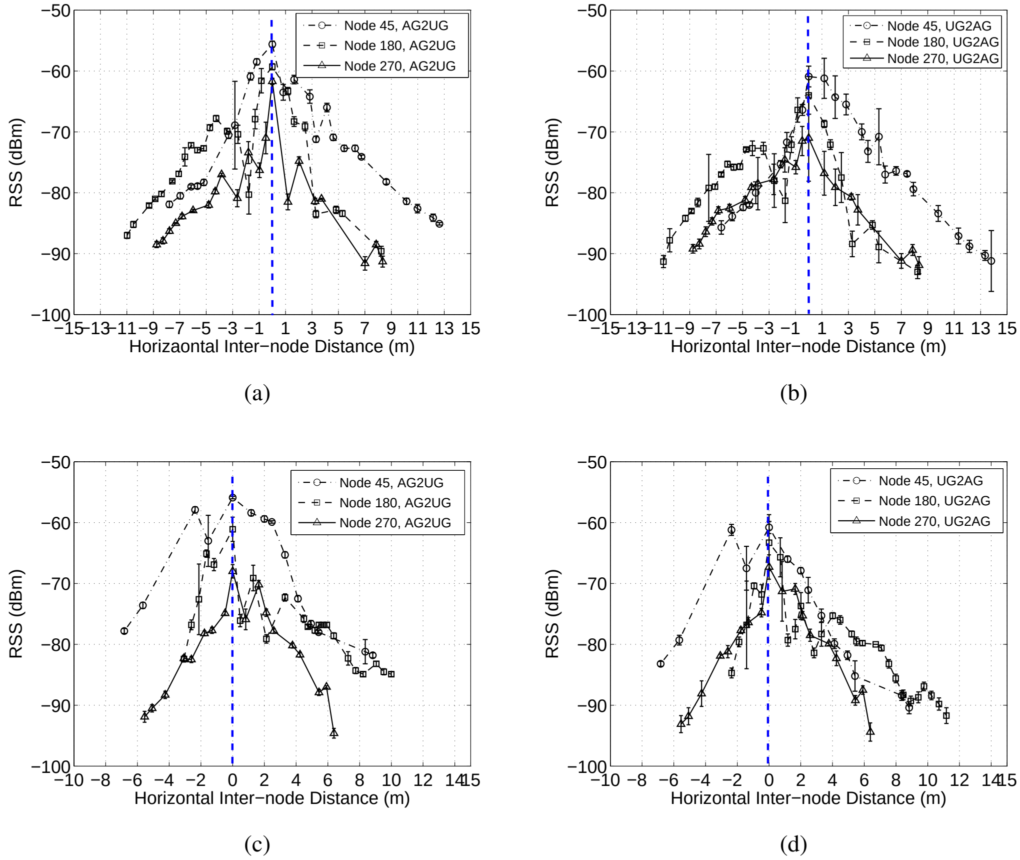


Figure 8: Effects of the horizontal inter-node distance on RSS: (a) AG2UG link (CW direction), (b) UG2AG link (CW direction), (c) AG2UG link (CCW direction), (d) UG2AG link (CCW direction).

is related to the conditions at a specific location rather than the movement of the CP. This is attributed to the irregularity of the soil surface due to plowing, the roots of crops, and the locations of crops with respect to the buried nodes. Accordingly, *semi-empirical* channel models are required to capture the dependacy on location in underground communication.

Next, we utilize channel models for AG2UG links and UG2AG links [10, 19, 22] to describe the characteristics of the AG2UG and the UG2AG communication. For both AG2UG and UG2AG links, the channel consists of two parts, the underground portion (soil medium) and the aboveground portion (air medium). Given the horizontal distance, d_h, the height of the AG antenna, h_a, and the burial depth of the UG nodes, h_u; the length of both portions can be calculated. Accordingly, the received signal strength at the receiver, P_r, is given as

$$P_r = P_t + G_t + G_r - \left(L_{ug}(d_{ug}) + L_{ag}(d_{ag}) + L_{(R,\rightarrow)}\right), \tag{2}$$

where P_t is the power of the transmitter, G_t and G_r are the antenna gains at the sender and the receiver, respectively. $L_{ug}(d_{ug})$ and $L_{ag}(d_{ag})$ are the loss at the underground and the aboveground portions, respectively, while $L_{(R,\rightarrow)}$ is the refraction loss based on the propagation direction $\rightarrow$.

The underground and aboveground losses are given as [10, 19, 22]:

$$L_{ug}(d_{ug}) = 6.4 + 20\log d_{ug} + 20\log\beta + 8.69\alpha d_{ug}\ ;\ \ L_{ag}(d_{ag}) = -147.6 + 20\log d_{ag} + 20\log f\ . \tag{3}$$

respectively, where β is the phase shifting constant shown in (1), and α is the attenuation constant, which is expressed as:

$$\alpha = \frac{2\pi c}{\lambda_0}\sqrt{\frac{\mu_r\mu_0\epsilon'\epsilon_0}{2}\left[\sqrt{1+\left(\frac{\epsilon''}{\epsilon'}\right)^2} - 1\right]}\ . \tag{4}$$

where ϵ' and ϵ'' are the real and imaginary parts of the soil dielectric constant.

Due to the higher dielectric constant of soil compared to that of air, the critical angle for the signals to propagate between these media is small. For UG2AG propagation, when electromagnetic waves propagate from soil to the air-soil interface, only the waves with small incident angle will transmit to air. Therefore, for the UG2AG channel, the waves propagate vertically in the soil and resemble a new source at the air-soil interface. For the AG2UG channel, the refracted angle is near to zero and the propagation in soil is also vertical. Thus, the underground portion of communication distance can be approximated as $d_{ug} \simeq h_u$, where h_u is the burial depth and the aboveground portion is $d_{AG} = \sqrt{h_a^2 + d_h^2}$, where h_a is the height of the AG node and d_h is the horizontal distance between nodes.

The refraction loss $_{(R,\rightarrow)}$ for the AG2UG link can be found as [19]: $L_{(R,ag2ug)} = 20\log((n\cos\theta_i + \cos\theta_t)/4\cos\theta_i)$, where θ_i is the incident angle, θ_t is the refracted angle and n is the refractive index of soil, which is given by $n = \sqrt{(\sqrt{\epsilon'^2 + \epsilon''^2} + \epsilon')/2}$. When the incident angle, θ_i, is small, $L_{(R,ag2ug)} \simeq 20\log[(n + 1)/2]$. For the UG2AG link, all energy is refracted and $L_{(R,ug2ag)} = 0$.

We apply the channel model in (2) to our experiment results to estimate the parameters α, β, and $L_{(R,\rightarrow)}$. Since the underground distance is assumed to be constant, the received signal strength in (2) can be rearranged as

$$P_r = -10\eta\log d_{AG} - \kappa - c\ , \tag{5}$$

where

$$\kappa = 8.69\alpha d_{ug} + 20\log\beta + L_{(R,\rightarrow)};\ \text{and}\ c = -P_t - G_t - G_r + 6.4 + 20\log d_{ug} - 147.6 + 20\log f, \tag{6}$$

and $c = 13.57$dB for the experiment parameters. To estimate the attenuation in air, η, and the soil-dependent component, κ, in (5), MMSE estimation is used and the results are shown in Table 3(a) and Table 3(b) for UG2AG and AG2UG links, respectively. The soil-dependent component, κ, is also found based on the Peplinski model [12] and the soil parameters in Table 1.

It can be observed from the MSE columns in Table 3(b) that the attenuation model in (2) accurately captures both links. On the other hand, there is a considerable variation in model parameters between different locations. The variation of the attenuation coefficient, η, is mainly due to the plants in the field, which cause reflection and attenuation in air. The variation of κ is caused by different values of α, β and $L_{R,\rightarrow}$ in different locations. Since those values are determined by the relative dielectric constant, ϵ, which depends on the soil characteristics such

Table 3: Estimated parameters

(a) UG2AG communication

node	$\hat{\eta}$	$\hat{\kappa}$	MSE
Approaching			
2	4.67	34.27	2.32
5	4.21	29.52	5.94
7	2.68	48.11	1.33
Departing			
2	4.05	29.70	1.52
5	5.25	34.19	3.70
7	3.30	47.42	1.51
Average			
κ_{model}		$\hat{\kappa}$	
48.59		40.78	

(b) AG2UG communication

node	$\hat{\eta}$	$\hat{\kappa}$	MSE
Approaching			
2	5.11	23.87	1.54
5	4.48	24.43	5.94
7	3.15	44.38	3.10
Departing			
2	3.53	31.52	2.03
5	5.58	27.35	3.57
7	3.84	42.43	4.74
Average			
κ_{model}		$\hat{\kappa}$	
55.50		38.46	

as volumetric water content (VWC), bulk density and soil composition, the variations of the values illustrate that even in the same field, the characteristics of soil vary from location to location. The model prediction of κ, i.e., κ_{model}, agrees well with UG2AG communication but is largely different for AG2UG communication. This suggests that the refraction loss, $L_{R,ag2ug}$, is not captured accurately. In addition, the model result is based on a soil measurement at a single point in the field and the spatial variance in soil properties leads to an error in model prediction.

5.3.3 Effects of Canopy and Soil Moisture

The growth of the crop causes an increase in the vegetation canopy and influences wireless communication [20]. In addition, soil moisture has an adverse effect on communication [3, 14]. In the following, we discuss the effects of these physical factors on communication based on Experiments A, B, and C as explained in Section 5.2. Experiment A is performed in dry soil without canopy whereas experiments B, and C are performed in wet soil without and with the canopy, respectively. In Fig. 9, the resulting RSS and PER values for both AG2UG and UG2AG links are shown for a horizontal inter-node distance of 3m.

The attenuation caused by the vegetation canopy can be investigated by comparing the results from Experiments B and C in Fig. 9. For both AG2UG and UG2AG links, canopy results in a 3dB increase in attenuation. This result agrees with previous studies [8, 20] and is important for the development of environmental-aware networking solutions. The attenuation caused by the variation in soil moisture can be investigated comparing the results from Experiments A and B in Fig. 9. An increase in volumetric water content from 16.6% (Experiment A) to 22.7% (Experiment B) results in a 3dB increase in attenuation.

6 Education and Training

The educational goals of this project are to integrate research challenges with course activities by bringing wireless sensor networks to the class, developing an interactive WSN testbed to encourage hands-on learning and organize yearly tech summer camps for "little farmers" to bring technology out to the field.

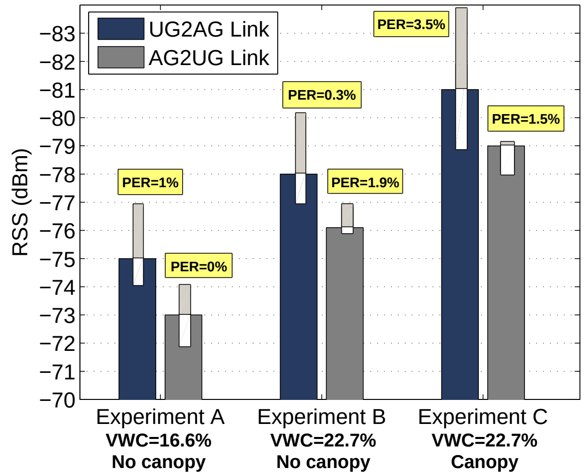
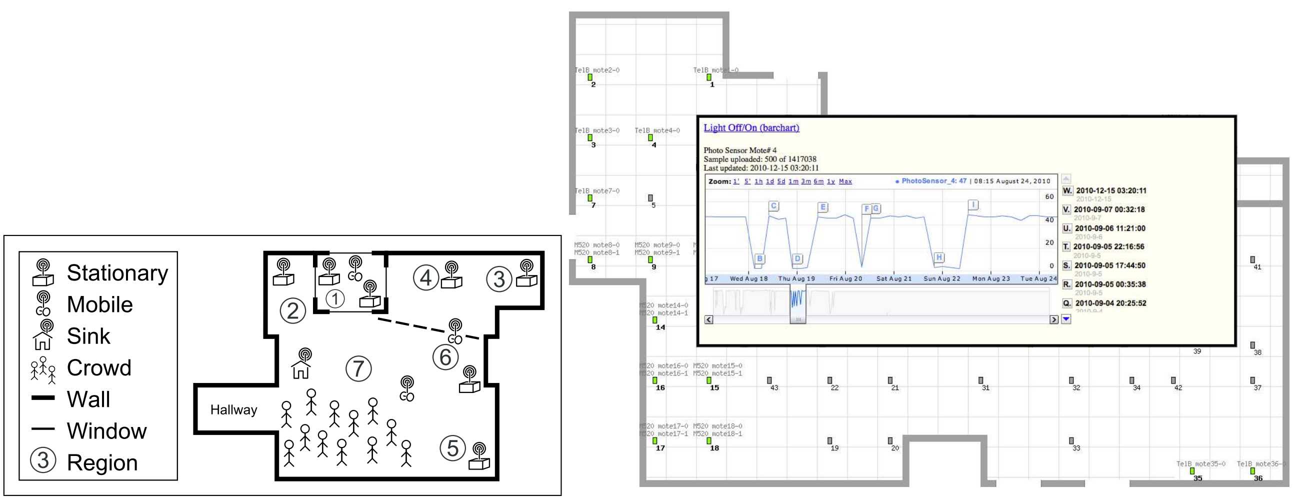


Figure 9: Effects of the vegetation canopy and the volumetric water content (VWC) for a horizontal inter-node distance of 3m.

6.1 Course Activities

The PI has been teaching undergraduate senior and graduate-level Embedded Systems and Sensor Networks courses, which include semester projects that enable the students to interact with WSN research challenges with a hands-on approach. Within the Sensor Networks course, concepts from wireless underground sensor networks have been integrated with the course curriculum and the recent results are discussed. These concepts have also been included in a recent **textbook on WSNs** co-authored by the PI that appeared in August 2010 [4].



(a) (b)

Figure 10: (a) Heterogeneous topology used for the Sparsely Distributed, Mobile WSN protocol with 7 regions. (b) Interactive testbed and sensor data visualization.

During this project, 8 projects have been completed and demonstrated by teams of undergraduate and graduate studens. Among these, the most related project, “Sparsely Distributed, Mobile WSN Protocol” is summarized next. This project focuses on WUSNs, which are sparse enough that sensor nodes cannot communicate with each other and must be deployed for an extended amount of time. The data delivery is performed through mobile nodes, which move in a limited area, where the combination of the areas of all mobile nodes covers the deployment field. This model applies to WUSNs, where main communication occurs between underground sensor nodes and aboveground mobile nodes.

The developed protocol focuses on the routing layer with two components: (1) a stationary to mobile protocol used to ensure the delivery of event data from the stationary nodes when requested and (2) a mobile to mobile routing protocol used to send event data between mobile nodes and eventually route packets back to the sink. The mobile nodes are assumed to be location aware and are confined to a limited area. Thus, multi-hop inter-mobile node communication is needed.

The mobile to stationary protocol attempts to minimize the energy consumed by stationary nodes by limiting the amount of time they spend awake and by sending packets only when absolutely necessary. Each stationary node wakes up periodically and listens for a wake-up packet sent by a mobile node. If the stationary node hears this, a data packet is sent to the mobile. For the mobile to mobile routing protocol, each mobile node keeps track of hops from sink count, reachable area, and *appointment book*. Accordingly, mobile nodes relay their data using other mobile nodes with lower hop counts in their neighboring areas according to the appointment book. The developed protocol is implemented in TinyOS using Mica motes and is demonstrated at the end of the course according to the setup in Fig. 10(a).

6.2 Cyber-physical Networking (CPN) Testbed

To facilitate the development of course projects, a large-scale wireless sensor network testbed was developed to be used both in teaching and research activities. Currently, 43 connection slots are attached to the ceiling, where an Ethernet and power supply infrastructure has been implemented above the ceiling. The inventory in the lab consists of over 200 sensor nodes as well as gateways; CMOS cameras and mobile robots, all of which are available to the students.

In this period, an undergraduate student is recruited through a UNL undergraduate creative activities and research experiences (UCARE) grant to develop a backbone to program and collect date from sensor nodes and design an interactive front-end for the testbed. As a result, the CPN Testbed supports remote programming, out-of-band monitoring, power management, and virtual sensing. A management software has been developed to streamline mote programming and real-time monitoring of the testbed. A screenshot of the developed backbone is shown in Fig. 10(b).

6.3 Tech Summer Camps

A summer camp module is being developed with the 4-H group [2] to be used within 4-H summer camps. The camp module includes a **mine sweeper** game, where the students will use Lego NXT robots to locate underground sensor nodes using wireless communication techniques. The NXT robots are integrated to Mica2 motes used for WUSN experiments. Using a combination of routing and wireless communication strategies, each team of students will try to *recover* all underground sensors, which listen to the wireless channel at a given duty cycle. The module will be first implemented and tested with the 4-H trainers and an initial deployment will be performed in July 2011.

7 Significance

The **significance** of the project include facilitating more efficient irrigation management technologies through real-time soil information provided by WUSNs. Through the development of an irrigation testbed, a proof-of-concept for integration of WUSNs with irrigation solutions is provided. Accordingly, water efficiency in crop production can be improved by utilizing the real-time soil information provided by WUSNs. The PI has disseminated the results of the research as a panelist in the UNL Water for Food conference, National Public Radio (NPR) news, MIT Technology Review journal, and Nebraska Farmer Magazine. Through these outreach activities, technological improvements in and the impacts of underground communication on agriculture are disseminated.

Within this project, 2 M.S. and 2 Ph.D. students are partly supported towards their dissertation. In addition, an undergraduate student is supported through a UNL UCARE grant and another undergraduate student will be supported through another UNL UCARE grant in 2011.

8 Publications Resulted from This Research

Journal Publications:

- X. Dong and M. C. Vuran, "$(\mathrm{CPS})^2$: Autonomous Precision Agriculture through Integration of Wireless Underground Sensor Networks with Center Pivot Systems," *submitted for journal publication*, 2011.
- X. Dong and M. C. Vuran, "A Channel Model for Wireless Underground Sensor Networks Using Lateral Waves," *in preparation*, 2011.
- A. R. Silva and M. C. Vuran, "Development of a Testbed for Wireless Underground Sensor Networks," *EURASIP Journal on Wireless Communications and Networking special issue on "Simulators and Experimental Testbeds Design and Development for Wireless Networks"*, vol. 2010, Article ID 620307, 14 pages, 2010.

Conference Publications:

- X. Dong and M. C. Vuran, "Spatio-temporal Soil Moisture Measurement with Wireless Underground Sensor Networks," in *Proc. IFIP Mediterranean Ad Hoc Networking Workshop (Med-Hoc-Net '10)*, Juan-les-pins, France, 2010.

- A. R. Silva and M. C. Vuran, "$(CPS)^2$: Integration of Center Pivot Systems with Wireless Underground Sensor Networks for Autonomous Precision Agriculture," in *Proc. ACM/IEEE Int. Conf. on Cyber-physical Systems (ICCPS '10)*, Stockholm, Sweden, 2010.

- A. R. Silva and M. C. Vuran, "Communication with Aboveground Devices in Wireless Underground Sensor Networks: An Empirical Study," in *Proc. IEEE Int. Conf. on Communication (ICC '10)*, Cape Town, South Africa, 2010.

References

[1] "Crossbow Mica2, Micaz, and IRIS motes," http://www.xbow.com.

[2] "4-H Youth Development," http://4h.unl.edu, March 2011.

[3] I. F. Akyildiz and E. P. Stuntebeck, "Wireless underground sensor networks: Research challenges," *Ad Hoc Networks Journal (Elsevier)*, vol. 4, pp. 669–686, July 2006.

[4] I. F. Akyildiz and M. C. Vuran, *Wireless Sensor Networks*. John Wiley & Sons, August 2010.

[5] X. Dong and M. C. Vuran, "Spatio-temporal soil moisture measurement with wireless underground sensor networks," in *IFIP Mediterranean Ad Hoc Networking Workshop (Med-Hoc-Net '10)*, Juan-les-pins, France, 2010.

[6] ——, "(CPS)^2: Autonomous precision agriculture through integration of wireless underground sensor networks with center pivot systems," *submitted to IEEE Trans. Indistrial Informatics special issue on "Cyber-Physical Systems and Cooperating-Objects: the New Frontier for Embedded Systems"*, 2011.

[7] H. D. Foth, *Fundamentals of Soil Science*, 8th ed. John Wiley & Sons, 1990.

[8] J. Giacomin and F. Vasconcelos, "Wireless sensor network as a measurement tool in precision agriculture," in *In Proc. XVIII IMEKO World Congress - Metrology for a Sustainable Development*, Rio de Janeiro, Brazil, September 2006.

[9] S. Irmak and et. al., "Watermark granular matrix sensor to measure soil matric potential for irrigation management,," UNL Extension Circular ECL783, 2006.

[10] L. Li, M. Vuran, and I. Akyildiz, "Characteristics of underground channel for wirless underground sensor networks," in *IFIP Mediterranean Ad Hoc Networking Workshop (Med-Hoc-Net '07)*, June 2007.

[11] U. Nations, "Coping with water scarcity - challenge of the twenty-first century," United Nations, United Nations - World Water Day 2007 Report, 2007, http://www.worldwaterday07.org.

[12] N. Peplinski, F. Ulaby, and M. Dobson, "Dielectric properties of soil in the 0.3–1.3 ghz range," *Geoscience and Remote Sensing, IEEE Transactions on*, vol. 33, no. 3, pp. 803–807, May 1995.

[13] J. Powell and A. Chandrakasan, "Differential and single ended elliptical antennas for 3.1-10.6 Ghz ultra wideband communication," in *Antennas and Propagation Society International Symposium*, vol. 2, Sendai, Japan, August 2004.

[14] A. R. Silva and M. C. Vuran, "Empirical evaluation of wireless underground-to-underground communication in wireless underground sensor networks," in *Proceedings of the 5th IEEE International Conference on Distributed Computing in Sensor Systems*, ser. DCOSS '09, June 2009, pp. 231–244.

[15] ——, "(CPS)^2: Integration of center pivot systems with wireless underground sensor networks for autonomous precision agriculture," in *Proc. ACM/IEEE Int. Conf. on Cyber-physical Systems (ICCPS '10)*, Stockholm, Sweden, 2010.

[16] A. Silva and M. Vuran, "Communication with aboveground devices in wireless underground sensor networks: An empirical study," in *Communications (ICC), 2010 IEEE International Conference on*, 2010, pp. 1–6.

[17] ——, "Development of a Testbed for Wireless Underground Sensor Networks," *EURASIP Journal on Wireless Communications and Networking*, vol. 2010, 2010.

[18] J. A. Stratton, *Electromagnetic Theory*. Wiley-IEEE Press, 2007.

[19] Z. Sun and I. Akyildiz, "Connectivity in wireless underground sensor networks," in *Proc. IEEE Conf. on Sensor Mesh and Ad Hoc Communications and Networks (SECON '10)*, 2010.

[20] A. Tavakoli, K. Sarabandi, and F. T. Ulaby, "Horizontal propagation through periodic vegetation canopies," *IEEE Trans. on Antennas and Propagation*, vol. AP-39, no. 7, pp. 1014–1023, July 1991.

[21] M. J. Tiusanen, "Wideband antenna for underground Soil Scout transmission," *IEEE Antennas and Wireless Propagation Letters*, vol. 5, no. 1, pp. 517–519, December 2006.

[22] M. C. Vuran and I. F. Akyildiz, "Channel model and analysis for wireless underground sensor networks in soil medium," *Physical Communication*, vol. 3, no. 4, pp. 245–254, 2010.

[23] M. Zúniga and B. Krishnamachari, "An analysis of unreliability and asymmetry in low-power wireless links," *ACM Trans. on Sensor Networks*, vol. 3, no. 2, pp. 1550–4859, June 2007.

[24] "Ward Laboratories," http://wardlab.com.

Information Transfer Program Introduction

The Water Center had another year of diverse and vigorous information transfer activities in fiscal year 2010. USGS funding continues to help underwrite a wide variety of information, public relations and education efforts, including: (1) four quarterly issues of the Water Current newsletter, which are mailed to more than 2,500 subscribers and also appears as an online pdf; (2) updated and reprinted Water Center fact sheets and University of Nebraska-Lincoln water faculty directory book and online database; (3) 30 press releases reporting on or promoting Water Center and UNL water-related research, outreach and educational activities; (4) support for the maintenance and regular upgrading of four internet web sites; (5) publicity and supporting materials for an annual water law conference, public lecture series, colloquium, water and natural resources tour to Colorado and Wyoming; and (6) faculty and staff retreats; (7) coordination of UNL's Extension's largest public display of the year at the Husker Harvest Days farm show.

Additional opportunities to expand and collaborate the Water Center's information transfer expertise will occur in the coming year as UNL begins forming the global Robert B. Daughtery Water for Food Institute, with its mission of greater global agricultural water management.

Information Transfer Plan/Water Education

Basic Information

Title:	Information Transfer Plan/Water Education
Project Number:	2008NE173B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	1
Research Category:	Not Applicable
Focus Category:	Education, None, None
Descriptors:	None
Principal Investigators:	Bruce Irvin Dvorak, Steven W. Ress

Publication

1. Newsletter: The Water Current newsletter has a free, subscriber-based distribution of approximately 3,100 copies per issue, more than 95% of which are requested subscriptions. It is published quarterly in a full-color magazine format, and is available online. Water-related research, engagement, education and outreach faculty and water-related professional staff are featured in each issue. Guest columns and articles are encouraged. A director's column is published in each issue. News Releases: The Water Center produces about 30 press releases annually focused on research results or progress, extension programming, educational opportunities, public tours, seminars, lectures, symposiums and conferences, awarding of major research grants and other matters of public impact involving the Water Center and other natural resource-focused UNL entities. These releases support a wide variety of UNL water-related research and outreach that cross departmental and academic disciplines. They focus on public impacts of UNL-sponsored research and programming. The UNL Water Center writes these for many UNL environmental science-related departments and faculty members who do not have a staff communicator available to them. The Water Center coordinates public media requests for information and interviews with sources on any water-related topic of interest to them and devotes significant attention to cultivating long-term relationships with members of the working media. The Water Center has a long reputation as a willing and reliable "source" among local, state and regional media for water and natural resources news. Media calls are frequent and water-related faculty and staff are accustomed to fielding questions from the media, doing radio and television interviews, etc. The Water Center makes wide use of electronic and broadcast journalism sources, as well as more traditional print (newspaper) sources.

Other Print Resources (all distributed free of charge):

Brochures and pamphlets: All full color. Updated and produced regularly as needed. These include, but are not limited to, mission and programming of the UNL Water Center, UNL Water Sciences Laboratory, Tern and Plover Conservation Partnership, annual Water and Natural Resources Tour and for other units or programs affiliated with or sponsored by the Water Center.

Water Center fact sheets: All full-color, generally one sheet. Used to inform and promote both general themes, such as the Water Center itself, or to announce specific programs, seminars, courses, etc. There are various editions, designed for specific internal and external audiences. The most widely distributed sheet in 2010 was to middle and high school students describing the wide variety of water-related careers.

Nebraska Water Map/Poster: A 24 x 36" full-color map of Nebraska, with a number of inset maps, diagrams and photos that describe the basics of water quantity, quality and use in Nebraska. The map is used for educational purposes on campus and across the state, and is available online.

A range of publications produced outside the UNL Water Center, particularly fact sheets, research project results and other print materials from USGS, Nebraska Department of Environmental Quality, U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, local Natural Resources Districts and University of Nebraska-Lincoln Extension, are available through Water Center and School of Natural Resources web sites or in print form. UNL Water Center assists with content, design, editing and production for many of these publications.

Electronic Resources:

Print materials produced by the UNL Water Center, and other information, are available online. The Water Center co-sponsors, designs and maintains the following related Internet web sites:

UNL Water:
http://water.unl.edu

UNL Water Center:
http://watercenter.unl.edu/

Water Sciences Laboratory:
http://waterscience.unl.edu

Conferences, Seminars, Tours, Workshops, and Other Outreach:

Water and Natural Resources Seminars: A longstanding annual series of 12 to 14 free weekly public lectures from January to April. The series includes a broad range of water related topics, such as irrigation and other agriculture topics, fish and wildlife, drinking water and wastewater, watershed management, modeling, energy, climate change, law, economics, and political science. In 2011 the series included a mini sub-series of four storm water management lectures, which was co-sponsored by the UNL Extension Stormwater Management Team. Individual lectures attract an audience of 60-100, including approximately 15 graduate and undergraduate students who attend the lectures as a one-credit seminar. Other audience members include faculty, additional students, government and nonprofit employees, policy makers such as state senators, and interested members of the public. News releases, mailings, brochures, posters and web-based information are produced supporting this long-standing series. Most lectures are posted online for out-state faculty and others.

Summer Water and Natural Resources Tour. The 2010 tour explored the North and Platte Rivers to their Colorado sources, including the massive reservoirs in Wyoming, and focused on water and irrigation issues along the Platte River in Nebraska, Colorado and Wyoming. The bus tour was sold out, with attendees including state legislators and congressional staff, faculty, and water scientists and managers from a wide variety of public and private entities. Co-sponsored by the Kearney Area Chamber of Commerce, Nebraska Public Power District, Central Nebraska Public Power and Irrigation District and others. News releases, mailings and a brochure are produced supporting this event.

Water Law Conference. A one-day conference focused on water law issues in Nebraska, such as water rights transfers, drainage issues, Clean Water Act enforcement, etc. The target audience for this event is the practicing bar, but approximately half of the 80 members of the 2010 audience were water managers and policy-makers, such as state senators. The program is developed by a committee that includes Nebraska's top water lawyers, and is co-sponsored by the University of Nebraska College of Law.

Greater Platte River Basins Symposium. This one-day event focused on water-related research and innovative programming in the Greater Platte Basins, which includes much of Nebraska. Noted USGS hydrologist Robert Hirsch opened the event with a talk on climate change impacts on water resources and management. Other talks and posters featured a wide variety of topics, including adaptive management, wetland restoration, water storage and overland runoff, water balance in riparian areas, endocrine disrupting chemicals in surface water, modeling, fish and wildlife, human dimensions of water management, drinking water and wastewater, flooding, etc. Attendance was about 125 and included faculty, students, and a wide variety of external scientists, water managers, policy-makers, etc. The event was co-sponsored by the USGS Nebraska Water Science Center.

Faculty/Staff Workshops, Networking and Mentoring Events: The Water Center is particularly focused on assisting faculty who are interested in interdisciplinary research. In addition to helping link individual faculty members to groups, the Water Center sponsored two events to help connect faculty. First was a half-day retreat on building interdisciplinary teams, with a particular focus on including human dimensions. Approximately 40 faculty and professional staff attended the event, which included tips for successful multidisciplinary teams as well as both structured and open networking time. Second was a networking event that included very brief research updates by a couple faculty members, but was primarily devoted to networking. Approximately 20 faculty attended.

The Water Center also prioritizes mentoring newer assistant professors to help them establish successful careers. The newer faculty from the many academic units associated with the Water

Center attended several brown bag sessions during the year where they could get acquainted and get advice from senior faculty or external partners on topics such as working with external stakeholders, multidisciplinary research, and managing large data sets over the course of a long career.

Other Outreach: Water Center staff routinely provide talks for groups and respond to requests for information. For example, during 2010 the Water Center coordinated faculty testimony and white papers for the Nebraska Legislature related to impacts of a new oil pipeline through the ecologically fragile Nebraska Sandhills and over the High Plains aquifer, the largest aquifer in North America.

Educational Displays:

The Water Center makes frequent public displays in association with conferences, symposiums, trade shows, educational open houses and water and environmental education festivals. Water Center staff make presentations and sit on steering committees for such annual educational and informational festivals as "Earth Wellness Festival," "Sunday with a Scientist, " "Gateway Farm Expo" and others. Water Center staff superintend UNL research exhibits at "Husker Harvest Days," one of the largest commercial agricultural expos in the country. More than 50,000 tour UNL exhibits during the three-day show.

Primary Information Dissemination Clientele:

U.S. Department of Agriculture
U.S. Environmental Protection Agency
U.S. Geological Survey
U.S. Bureau of Reclamation
U.S. Army Corps of Engineers
U.S. Bureau of Land Management
Nebraska Department of Natural Resources
Nebraska Department of Agriculture
Nebraska Health and Human Services System
Nebraska Department of Environmental Quality
Nebraska Environmental Trust Fund
Nebraska Association of Resources Districts (and 23 individual NRDs)
Nebraska Congressional delegation
Nebraska State Senators
Public and private power and irrigation districts
The Audubon Society
The Nature Conservancy
Nebraska Alliance for Environmental Education
Nebraska Earth Science Education Network
Other state Water Resources Research Institutes
University and college researchers and educators
NU students
Public and parochial science teachers

Farmers
Surface and groundwater irrigators
Private citizens

Cooperating Entities: (LBB: I didn't do anything with this section since Tricia was making notes on additions)

In addition to primary support from the USGS, the following agencies and entities have helped fund communications activities by the UNL Water Center during the past year.

U.S. Environmental Protection Agency
U.S. Department of Agriculture
Nebraska Department of Environmental Quality
Nebraska Research Initiative
Nebraska Game and Parks Commission
National Water Research Institute
Nebraska Public Power District
Central Nebraska Public Power and Irrigation District
Farm Credit Services of America
Kearney Area Chamber of Commerce
Nebraska Association of Resources Districts
UNL Institute of Agriculture and Natural Resources
UNL Agricultural Research Division
UNL College of Agricultural Sciences and Natural Resources
UNL School of Natural Resources
UNL Water for Food Institute
University of Nebraska College of Law
USGS Nebraska Water Science Center
Nebraska Center for Energy Sciences Research

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	0	0	0	0	0
Masters	2	0	0	0	2
Ph.D.	4	0	0	0	4
Post-Doc.	0	0	0	0	0
Total	6	0	0	0	6

Notable Awards and Achievements

Mr. Agnelo Silva was awarded Milton E. Mohr Fellowship by UNL College of Engineering based on his work supported by this grant.(2010NE209B)

A competitive undergraduate research grant (UCARE) was awarded to Mr. Tanner Dozark for summer 2011 to develop education modules for underground communication for the 4-H program based on results gathered in this project. (2010NE209B)

Mr. Agnelo Silva was awarded the Outstanding Poster Presentation award for his work titled "Wireless Underground Sensor Networks for Autonomous Water Management" in Water for Food Conference 2010. (2010NE209B)

A competitive undergraduate research grant (UCARE) was awarded to Mr. Cheney So during summer 2010 to develop an interactive sensor network testbed. (2010NE209B)

A competitive undergraduate research grant (UCARE) was awarded to Ms. Katherine Boone on the basis of her proposal to work on this project. (2010NE199B)

Epscor Funds of $19,850 were awarded in addition to funds received from USGS 104b (2010NE199B)

A competitive departmental assistantship was awarded to Ms. Taryn Serwatowski on the basis of her proposal to work on this project. (2010NE199B)

Publications from Prior Years

1. 2008NE168B ("Fate of microcontaminants in streams augmented by wastewater treatment plant effluent use") - Articles in Refereed Scientific Journals - Bartelt-Hunt, S.L., Snow, D.D., Damon-Powell, T., Brown, D.L., Prasai, G., Schwarz, M., and Kolok, A.S. (2011). Quantitative evaluation of laboratory uptake rates for pesticides, pharmaceuticals and steroid hormones using polar organic chemical integrative samplers. Environmental Toxicology and Chemistry, DOI: 10.1002/etc.514